PROBLEM SOLVING IN CHEMISTRY AT SECONDARY SCHOOL

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Abstract

Problem solving happens in every field of human enquiry and form of knowledge. There are many problems in areas that are artistic, philosophical, linguistic, journalistic, legal or medical. Indeed, these problems have to be solved just as much as those in mathematics, science and technology. Life is a problem solving process.

While most significant real-world problems are ill-defined, problem solving at school level tends to be limited to a training in various exercises and algorithmic processes. In life, problems tend to be more multi-faceted and open-ended, rarely having a single or final solution. Indeed, if education is to prepare pupils for life, then the skills of problem solving, where the problems are open-ended, must be considered as an area of high priority.

In this project, the nature of open-ended problem solving is explored and working descriptions presented. In order to study the ways by which secondary pupils (ages 14-17) seek to solve open-ended problems in chemistry, a set of eighteen problems was devised. These were used with several hundred school pupils and data was gathered to examine the nature of difficulties experienced in facing such problems.

The set of problems (described as units) was designed to be difficult and pupils worked in groups of three to seek solutions. They were encouraged to discuss the problem as they tried to solve it and to make notes of their attempts at solution. After each problem, they completed an assessment individually where they were asked to reflect on the process through which they had moved as they tried to solve the problem. Tape recordings of the discussions of many groups of pupils were made and other observations were made to build up a more complete picture. The information obtained was analysed and summarised to seek to gain insights into the process of problem solving where the problems were open-ended, unfamiliar and difficult. The main area of interest was to explore the way long term memory affected problem solving in such situations.

Pupils enjoyed the units and liked working in groups. They tended to perceive the problems as difficult because they were unfamiliar and they felt they did not have enough knowledge. In fact, all the units were based specifically on the syllabus content and, therefore, pupils should have had enough knowledge. Nonetheless, they felt a knowledge inadequacy. It is possible that this observation might be linked to the lack of long term memory connections between islands of knowledge: while they should have known the key facts, perhaps the way they were required to link them to solve the problem was itself a major source of difficulty.

In many units, the difficulty is clearly related to the feeling of pupils that they were unsure that they had the "right" answer. This probably reflects the fact that the units were very different in character from their previous experiences where "right" answers

may have been encouraged. Insecurity seems to be related to perceived difficulty.

It was found that the S5 pupils were very much better in discussion and had very much greater confidence than the S4 and S3 pupils. However, they were not much more successful in solving problems. It appears that their greater chemistry knowledge background gave them greater confidence in discussing the given task.

Quite a number of areas of difficulty related to the demands arising from specific areas of chemistry. For example, the way chemical equations can be interpreted and applied was an area where confusion was seen very clearly: pupils could write them and balance them but had very variable understanding of what they meant.

It was found that pupils rarely planned; they just started with what they could do. This lack of planning was very evident in the way they handled the problems, even when encouraged to to do so. When faced with an amount of unfamiliar information, pupils tended to lose confidence and seemed very unsure how to tackle a problem. Pupils' unease and insecurity also occurred when faced with ambiguous data where there were no unequivocal answer or approaches. Confidence is a very important factor in success in problem solving.

Although working in groups and being encouraged to make notes throughout was designed in order to minimise difficulties due to limitations in working memory space, in one or two problems information overload was observed as a major source of difficulty.

In looking at long term memory, it was very clear that absence of key information (facts, concepts or processes) posed a major difficulty. However, it was noted that correct information, inappropriately applied, could also be a significant difficulty. One area of difficulty pupils frequently encountered was in bringing various parts of information and knowledge together. This suggests that the creation of mental pathways between "islands" of knowledge or skills is extremely difficult. It seems that learners cannot make linkages between key concepts and the links must be suggested or supplied by the teacher in some way.

Specific evidence gained suggested that by learning a procedure in one direction, there is no guarantee that it can be applied in the opposite direction. This suggests that links in long term memory need to be made in both directions in order for the linkage to be soundly made. If the key concepts are partially grasped, then approaches to problem solving were confused and the problem solver was not even be aware of the confusion. In such situations, pupils started to generate explanations which mixed error with truth.

Overall, the evidence supports the ideas suggested by an information processing model and raises major questions about whether problem solving can be taught or whether it is a generic skill at all. The conventional use of problem solving in curriculum documents also needs major re-thinking in the light of the picture gained.

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Introduction

1.1 The Enormous Significance of Problem Solving in Life

Problem solving happens in every field of human enquiry and form of knowledge. Typical problems in our life include finding a way to pay the bills, discovering a flat tyre and wondering what to do about it or finding a shortcut to avoid a traffic jam. In addition, when confronting social, technological, or political problems, people need to make a conscious decision and take responsibility for the consequences of their actions. There are many problems in areas that are artistic, philosophical, linguistic, journalistic, legal or medical. Indeed, these problems have to be solved just as much as those in mathematics, science and technology. As a result we can say that life is a problem solving process.

Glover *et al.* (1990) asserted that most significant real-world problems are ill-defined. They also tend to be more multi-faceted and open-ended. Such problems rarely have a single or final solution, most of them only have a variety of possible approaches rather than an exact outcome. Teachers and schools need to provide many opportunities for pupils to study these kinds of ill-defined and open-ended problems and learn how to use science to solve crucial everyday problems. Indeed, if education is to prepare pupils for life, then the skills of problem solving, where the problems are open-ended, must be considered as an area of high priority.

1.2 The Definition of Problem Solving

Frequently, a problem has been represented as: well-defined, ill-defined; closed or open-ended. Before exploring the definition of problem solving further in the context of this project, it is essential to know what is the difference between problem and exercises and what is the meaning of well-defined / ill-defined problems and closed / open-ended problems.

1.2.1 Problems and Exercises

In contrast to real-life problems, most problems presented at school tend to be well-defined. They tend not to be open-ended and they focus on one right answer. Is this kind of problem a real problem or just an exercise? It is certainly necessary to distinguish between problems and exercises. Hayes (1981) defined a problem as what exists "whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap". This approach suggests that if you know what to do when you read a question, it is an exercise not a problem.

As Kahney (1986) claimed, the distinction between well-defined problems and ill-defined problems is in terms of how well they are defined. In a well-defined problem, the solver is provided with all the information which including the initial state, goal state, and what he calls the operators and operator restrictions at the start of the problem. An ill-defined problem is one in which information about either the initial or goal state, or the method of solution, is incomplete. In short, in ill-defined problems the solver has to define the problem for himself, that is, the degree of structure depends on the solver's own knowledge. As regards the closed or open-ended problem, the former means the problem only has "a unique solution" and the latter means it may have "a variety of solutions".

In an early study looking mainly at problems that tended to be more like exercises or applications, Ashmore, Frazer and Casey (1979) classified chemical problems on two dimensions, namely the nature of the solution required (goal state) and the sources of information (initial state) which must be employed. In their views, a problem situation ranged from "chemical puzzles" (where there is a unique answer and the information is given in the problem statement) through to the highest levels of research work (where the answer may not be unique and the information must be generated by observation or experimentation). They suggested that when defining problem solving it must encompass this wide range of problem situations.

1.2.2 The Definition of Problem Solving

The term of problem solving is defined in the Dictionary of Education (Lawton and Gordon, 1996) as "a style of teaching or learning where the aim is to encourage pupils to acquire knowledge and skills in the process of solving problems rather than simply learning about how other people have solved such problems".

Different writers have defined problem solving in a variety of ways. According to Wheatley (1984), problem solving is defined broadly as "what you do when you don't know what to do". Gagne (1977) stated that problem solving can be viewed as a thinking process by which the learner discovers a combination of previously learned rules that he can apply to solve a novel problem; it is also a process that yields new learning. Ashmore *et al.* (1979) defined problem solving as the result of application of knowledge and procedures to a perceived problem. Spanish academics Gil Perez and Martinez Torregrosa (1983) saw problem solving as a scientific investigative task in their research work in physics. Mayer (1997) viewed problem solving as almost synonymous with thinking. Ausubel (1978) defined problem solving as a form of meaningful discovery learning, but not a completely autonomous discovery. He insisted that no frequently practised procedure or strategy could be called problem solving. In fact, problem solving is a type of learning in which problem conditions and desired objectives are substantively related to existing cognitive structure.

In this project, problem solving is defined as "when a person encounters an open-ended or unfamiliar situation, problem solving is the process where the person uses knowledge and thinking skills to reach a solution".

Other viewpoints about problem solving from within the Scottish educational system have been proposed. The Scottish Qualifications Authority (1997) set up a list of Problem Solving Abilities to analyse what pupils need to be able to do for success in Problem Solving. The abilities assessed are listed as follows:

Selecting information
Presenting information
Selecting procedures
Concluding and explaining
Prediction and generalising

While each of these abilities is frequently required in problem solving, collectively they cannot claim fully to enable a student to undertake any possible problem solving. There are clearly definable gaps in the list. For example, selecting procedures implies that procedures are known whereas in most open ended problems such as real life problems, procedures need to be developed. The list certainly seems to be somewhat limited and selective.

It is necessary to examine whether these Problem Solving Abilities can be seen as comprehensive and duly reflect the essence of problem solving. In many examination papers, certain questions are identified by the examiner as testing problem solving skills. Looking at many of these questions would leave the observer with the impression that the questions do not really test problem solving but demonstrate pupil abilities to apply knowledge in a routine way. They could be described as algorithmic in nature. The most clear examples occur in mathematics where problems are really just exercises - routine solutions being achieved by the use of learned algorithms. A typical example from science illustrates the kind of problems that are most frequently found.

The following question (overleaf) comes from a previous examination paper (Standard Grade Chemistry, 1996) and the examiner identified the question as testing problem solving skills.

Coloured solutions can be made from fruits and flowers.
The colours of these solutions can be affected by pH.

		pH		
Solution		*Less than 7*	*7*	*Greater than 7*
A	*hydrangea*	*pink*	*blue*	*yellow*
B	*marigold*	*orange*	*orange*	*orange*
C	*rose*	*pink*	*pink*	*yellow*
D	*strawberry*	*red*	*red*	*green*

*(a) Identify the solution which gives a **different** colour with hydrochloric acid and with sodium chloride solution.*

*(b) Identify the solution which is not **suitable** for showing the difference between an acid and an alkali.*

To reach an answer for the question, pupils just compare the colours in different pH and the solution becomes quite obvious. It is not a real problem but just an opportunity for pupils to demonstrate an application of knowledge or skills in a routine way. Indeed, little chemistry knowledge is required: the question is nearly just a test of logic.

1.3 Problem Categories

Problems have been categorised in several different ways. Greeno and Simon (1978, 1988) suggested a four-part typology of problems:

(1) Problems of transformation: the problem-solving process was described as "searching through a set of possibilities."

(2) Problems of arrangement: they were regarded as design problems and the problem-solving process was described as "narrowing the set of possibilities."

(3) Problems of inducing structure: the problem-solving process was described as "finding a general principle or structure."

(4) Evaluation of deductive arguments: they viewed that "psychological analyses provide no evidence for a belief in deductive reasoning as a category of thinking processes different from other thinking processes."

They also pointed out that not all problems can be neatly classified into one of these types. Instead, some problems include aspects of several types of problems.

A more thorough classification of problem types has been made by Johnstone (1993). He suggested that there are three variables associated with all problems: the data provided, the method to be used and the goal to be reached. By looking at the extremes where each variable is either known or unknown, he came up with eight problem types. The eight types of problem are shown as below (Table 1.1).

Table 1.1 Classification of Problems (Johnstone, 1993)

Type	Data	Methods	Goals/ Outcomes	Skills Bonus
1	Given	Familiar	Given	Recall of algorithms
2	Given	Unfamiliar	Given	Looking for parallels to known methods
3	Incomplete	Familiar	Given	Analysis of problem to decide what further data are required
4	Incomplete	Unfamiliar	Given	Weighing up possible methods and then deciding on data required
5	Given	Familiar	Open	Decision making about appropriate goals. Exploration of knowledge networks
6	Given	Unfamiliar	Open	Decisions about goals and choices of appropriate methods. Exploration of knowledge and technique networks
7	Incomplete	Familiar	Open	Once goals have been specified by the student, these data are seen to be incomplete
8	Incomplete	Unfamiliar	Open	Suggestion of goals and methods to get there; consequent need for additional data. All of the above skills

Type 1 and 2 are the "normal" problems usually encountered in textbooks and exam papers. Type 1 is of the algorithmic nature and can be regarded as an "exercise". Types 3 and 4 are more complex, with type 3 seeking data while type 4 requiring very different reasoning from that used in types 1 and 2. Type 5 to 8 have open goals, and are very demanding. Indeed, the type 8 problem is the nearest to real life problems but not necessarily more difficult than any other type. In fact, Johnstone never intended that the eight types would be seen as hierarchical. Thus, he did not imply that anyone proceeds from type 1 to type 8 as a kind of development in problem solving. This is a most useful classification, being simple and relatively easy to apply and understand. Therefore, it is considered as one way to sort out problem types in this project.

1.4 Problem Solving and The Bloom Taxonomy

In Scottish school syllabuses today at Standard Grade (ages 14-16), problem solving is a specific outcome that is frequently listed. For example, in all the science syllabuses (Scottish Qualifications Authority, 1997) as well as syllabuses in many other areas (like Computing, Home Economics, Technology, Social and Vocational Skills), problem solving is a listed outcome attracting a significant proportion of the marks for final accreditation.

In previous syllabuses (Scottish Examination Board, 1962) such as the Ordinary Grade (discontinued in the early 1970s), a common feature was to use the Bloom Taxonomy (1956) as a basis for describing educational outcomes. In this taxonomy, Bloom described six cognitive skills:

Evaluation
Synthesis
Analysis
Application
Comprehension
Knowledge

The tendency is to assume that these six skills are hierarchical. Thus, for example, the skill of application depends on being able to comprehend relevant knowledge, while evaluation depended on the use of the five other skills. Frequently, the "top" three skills are described as "higher order skills" (Garrat, 1998), implying that these skills are more advanced in some way when compared to the "lower" three skills. Perhaps these three skills are one way of thinking about problem solving in that, in problem solving that is not algorithmic, the skills of analysis, synthesis and evaluation may be very important.

Bloom has pointed out that problems requiring knowledge of specific facts are generally answered correctly more than problems requiring knowledge of the universals and abstractions in a field. Moreover, problems requiring analysis and synthesis are more difficult than problems requiring comprehension. It is possible to look at the Bloom taxonomy (Figure 1.1, overleaf) in an alternative way. In other words, this does NOT assume that the skills are hierarchical. Instead, knowledge is seen as the basis for any of the other five skills.

It is possible to use this modification of Bloom's taxonomy as a way to describe problem solving. For example, the solving of algorithmic problems can be thought of as an application where the pupil is applying some learned procedure using new data. More open ended, real-life problems can be thought of as one or more of analysis, synthesis and evaluation. The important point to note, however, is that all these cognitive skills depend on knowledge.

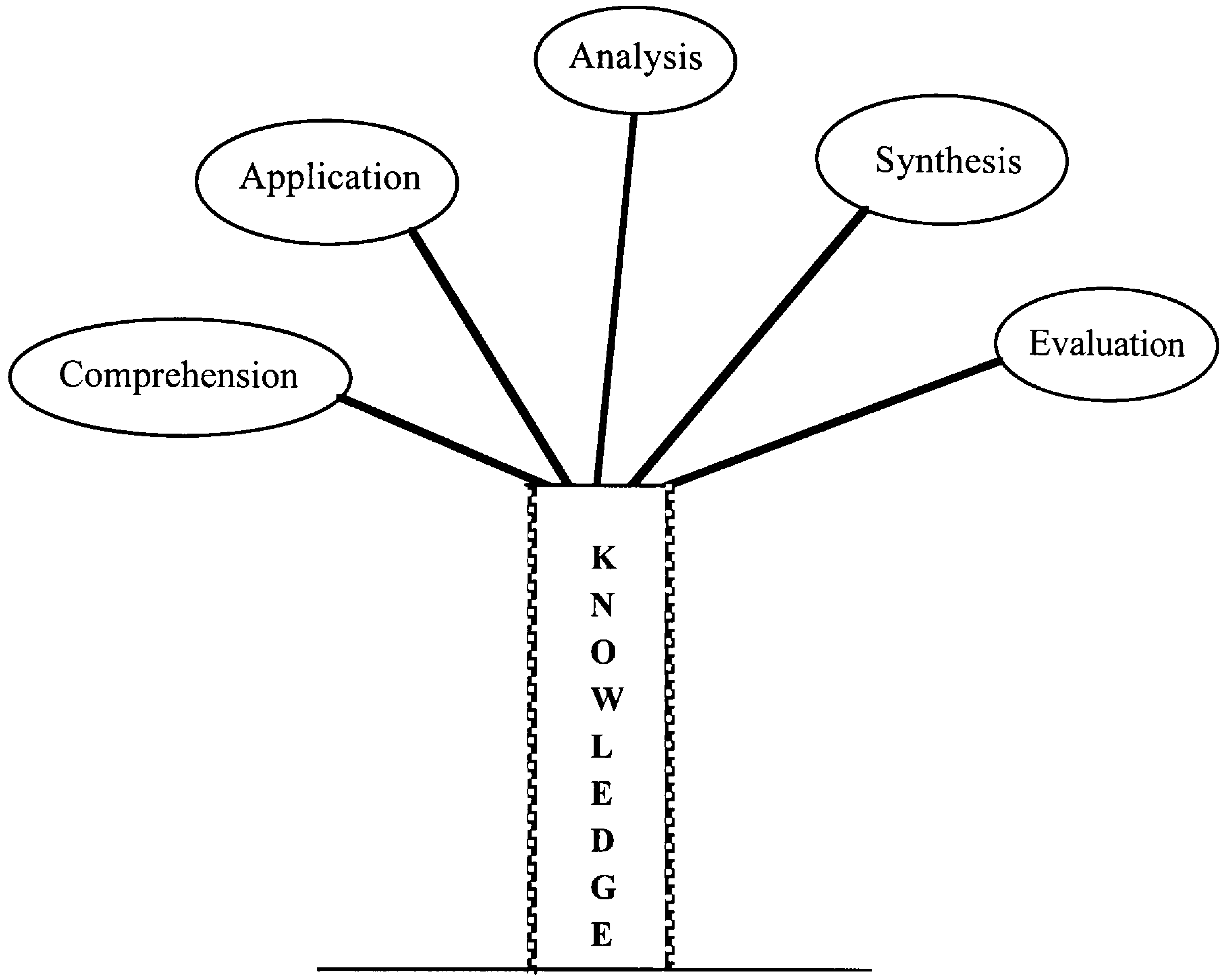

Figure 1.1 An Alternative Model

1.5 The Role of Knowledge in Problem Solving

Psychologists view that knowledge is at the core of human cognition. It not only underlies all cognitive activities but also influences problem solving. According to Glover *et al*. (1990), a strong assertion was proposed that problem solving is knowledge based. However, having knowledge does not ensure problem-solving skills. Furthermore, they also pointed out that three types of knowledge are important to undertake complex tasks such as problem solving. These three types of knowledge are described as follows.

(1) Domain-specific knowledge: it is knowledge specific to performance of a particular task.

(2) General knowledge: it refers to knowledge that is not domain-specific, but essential to utilisation of domain-specific information.

(3) Strategic knowledge: it focuses on how domain-specific and general knowledge should be organised and sequenced for effective use.

Mayer (1997) identified five kinds of domain-specific knowledge, which are necessary for solving mathematical story problems. These are listed below.

(1) Linguistic knowledge: recognising words, parsing sentences, etc.
(2) Semantic knowledge: knowledge of the world relevant to the problem.
(3) Schematic knowledge: knowledge of problem types.
(4) Procedural knowledge: knowledge of the algorithms necessary for problem solution.
(5) Strategic knowledge: techniques for using types of knowledge and heuristics.

1.6 The Aims of this Project

The aim is to explore problem solving with school pupils of ages 14-17. These pupils are following Chemistry courses at Standard Grade or Higher Grade. It is recognised that there may be many factors that influence success in solving problems of a non-algorithmic nature. One of these is likely to be knowledge and how it is used. On this basis, the following questions are raised:

1. If pupils do not have the key chemistry knowledge, problem solving will be more or less impossible. Does the way the knowledge is gained and stored affect success in problem solving?

2. Sometimes, solving a problem may need to bring several pieces of knowledge together. A problem solver may be hindered if these pieces of knowledge are not linked or are not linked in the correct way. Are pupils able to create a pathway or make appropriate linkages between islands of knowledge?

3. Pupils' confidence is likely to be important when they encounter new types of problem, especially when the given data are ambiguous and the method of approach is unfamiliar. Is it possible to minimise the effects of lack of confidence which might hinder problem solver success?

In fact, many other factors will be involved in influencing success in problem solving. Limitations in working memory space as well as psychological factors such as field-independence and divergence may be important. In seeking to explore the way that long term memory may influence problem solving success, those other fctors will be minimised by group work.

Chapter Two

Theories of Learning and Problem Solving

In a sense, life is all about solving problem, problems which are open ended in some measure. In solving such problems, experience is gained and learning can take place. It is, therefore, reasonable that learning theories may have a major contribution to make in understanding how problem solving skills are developing. However, many theories have been developed in learning contexts that are very different from the open-ended type of situation envisaged here. Therefore, in reviewing briefly contributions from learning theories, only those models which can be seen to be linked to open-ended problem solving situations are discussed and the contributions to understanding learning in any overall sense are not discussed in a comprehensive way. Only those observations that seem relevant to problem solving are considered.

2.1 What Is Learning?

In general, learning has occurred when our behaviour or attitudes have been changed or modified. Although learning has various definitions, most psychologists and educators tend to agree that "learning is a process by which behaviour is either modified or changed through experience or training". It refers not only to an outcome that is manifestly observable, but also to attitudes, feelings, and intellectual processes that may not be so obvious (Hamachek,1995). Learning can also be defined as improvement in behaviour, but that does not imply that one's behaviour improves from the standpoint of desirability.

2.2 Two Leading Learning Approaches

Learning theories have been classified into two major groups: Behaviouristic theories and Cognitive theories. These two groups both agree that learning result in a modification or change in behaviour based on experience, but there are two areas of debate where they do not approach learning in the same way. They have different viewpoints as describing: *(1) how learning occurs; (2) how to best establish the conditions that maximise learning in the first place.*

Behaviouristic theories have been known as stimulus-response theories (S-R theories). For behaviourists, learning is a change in observable behaviour, which occurs through stimuli and responses. They interpret learning in terms of changes in strength of S-R connections, associations, habits, or behavioural tendencies. For cognitive theorists, learning is likely to be holistic. Learning is a process of gaining or changing insights, outlooks, expectations, or thought patterns. They define learning in terms of reorganisation of perceptual or cognitive fields so as to gain *understanding* (Bigge and Shermis, 1999).

Behaviourists do not discuss what is happening internally as learning occurs but concentrate on the stimuli and the responses. Cognitive theorists, on the other hand, are involved with the internal mechanisms that bring about learning. In fact, these two theories both have their value in education. Behaviouristic theories help us to define the conditions under which particular types of learning must be broken into smaller subunits. Cognitive theories help us understand the need for developing a broad cognitive structure in coping with specific learning tasks.

2.3 Piaget's Theory of Cognitive Development

Jean Piaget (1896-1980) is one of the best well-known developmental psychologists. His most important contribution is the "theory of cognitive development" which was obtained from the detailed observations of his own children.

2.3.1 Stages of Development

As he defined, there are four stages of cognitive development named:

(1) *sensori-motor stage (age 0-2): children using grasp, suck or look at objects to develop their internal representation.*

(2) *pre-operational stage (age 2-7): at this stage, children can remember, imagine and pretend.*

(3) *concrete operational stage (age 7-11): during this stage, children begin to learn to handle the basics of logical thought but still relied on the real concrete objects. That is, they can perform mental operations with concrete materials but not with abstract possibilities.*

(4) *formal operations stage (age 11 plus): at this stage, pupils are mentally able to solve abstract problems; their logical processes move into abilities to handle abstract ideas with the formation of hypotheses.*

All children develop their cognitive structure (construct their own knowledge) through these stages in the same order but not at the same rate. As each stage unfolds, the pupil is able to understand a more complex view of the world.

One extremely important Piagetian concept which is useful in education is "*equilibrium*". Cognitive development can be seen as a period of dis-equilibrium followed by adaption when the child changes his or her present cognitive structure to fit a new environment. The process of adaptation occurs through two complementary mechanisms: *assimilation* *and accommodation.* In Piaget's view, the child is seen as an organism growing in an environment that influences development. The child adapts to surroundings, absorbing (he calls *assimilation*) what is required for cognitive growth and changing (*accommodation*) behaviour as necessary (Hyde, 1970). He viewed that cognitive development is a logical series of what he calls "equilibrations" which are constant adjustments of the balance between assimilation and accommodation (Flavell, 1963). In Novak's study (1978), he also suggested the accommodation process takes place simultaneously with the assimilation process, when the new experiences lead to the modification and alteration of the learner's thought patterns.

Piaget regarded learning as an activity with that stages of cognitive development which are biologically determined and that cannot be changed. Among those four stages of cognitive development, only the latter two stages (3 and 4) are significant in secondary education. At the age of some of the pupils involved in this project discussed (ages 14-17), pupils are likely to be operating cognitively with the formal stage at various levels of development. This may mean that the handling of abstract ideas and the ability to pose alternative ways of looking at information may not be well developed. Indeed, there is evidence that first year university students are not necessarily operating fully at the formal stage although they might be capable of it (Herron, 1975).

2.3.2 The Validity of Piaget's Theory

Although Piaget's development theory provides an underpinning framework for education, his findings are limited in that they describe children's thinking and reasoning at the concrete operational level, with only a few descriptions bordering on the formal operational stage (Bliss, 1995). Thus, there has been many doubts about the validity of Piaget's development theory. Critics of Piaget have noted his boundaries are far too rigid, his conclusions being based on poor sampling. It appears that the child's experience and environment are far more powerful influence on their cognitive development than Piaget allowed (Bruner, 1996). Recently, Bliss (1995) makes a clear point that three challenges to Piaget are particularly relevant to science education, they are:

(a) *queries about the appropriateness of the description of "formal operations": many educators have argued that the formal operational stage did not describe appropriately the thinking and reasoning of most secondary school pupils.*

(b) *the realisation of the importance of domain specific knowledge, rather than general operational schemes;*

(c) *the realisation of the importance of the socio-cultural context of learning, that is the situatedness of learning.*

Such questions have been examined by many researchers. For instance, the results from Wason's studies (1966, 1978, 1984) have shown that even highly educated adults perform badly on tasks involving abstract hypothetical thinking. Keil (1986) and Carey (1985) saw adults as different from children mainly by knowing more, not by possessing different general cognitive structures. Carey claimed further that once domain specific knowledge have been studied in children's own right, then it would possible to sort out the nature of general development and its constraints.

The importance of the socio-cultural context of learning is accepted and it is influenced by Vygotsky's (1974) ideas. A typical example is from Wood's study (1991), he followed Lave, Murtaugh and Rocha's idea: *children's strategies for solving "similar problems" depends on the environment where they encountered the problems,* and suggested that when adults and children in different context (e.g. home and school) doing similar things, the processes involved are dissimilar. This suggests that problem solving skills are context dependent and are not generic in nature.

Similarly, Fox (1994) also reported that there are two critical issues involved with Piaget' theory. Firstly, it can be argued that many of changes observed by Piaget are basically changes in children's thinking due to developments in their language. On the contrary, Piaget believed that it is the cognitive structure changes first and the language development just stems from the changes in cognitive development. The second issue is whether the four stages are an accurate reflection of children's cognitive development. Bruner's (1959) believes that there are other stages of development once a child reaches 11. However, although such criticisms emerged, Piaget still has to be considered as one of the outstanding cognitive and developmental psychologist of all time.

2.4 Lev Semyonovich Vygotsky: Language and Thought

The Russian psychologist, Vygotsky (1974), found that social and cultural interaction was the key to success in learning. He rejected the view that intelligence was fixed. On the contrary, he claimed that all children have a potential for development in collaboration with others. His well-known social-cognitive theory is characterised by three underlying themes: *(a) the importance of culture; (b) the role of language; (c) the idea of a zone of proximal growth.*

Vygotsky thought that human learning had a social characteristic and that children grew into the intellectual life of their peers. When children interact with more capable peers or adults, under these people's assistance they will be able to solve more problems on their own. Culture obviously plays an important role. As regards "*language*", he stressed that children begin to use language, not only as a means to communicate with others, but also to plan and guide their own activities.

In his book "*Language and Thought*", Vygotsky (1974) proposed the idea of "*the Zone of Proximal Development* (ZPD)" and defined it as *"the discrepancy between a child's actual mental age and the level he reaches in solving problems with assistance"*. By giving harder problems to two aged 8 children and providing them with some slight assistance, he discovered that one child could, in cooperation, solve problems designed for twelve-year-old, while the other could not go beyond problems intended for nine-year-old. This result suggested that every child has his or her own "*zone of proximal development*". This refers to potential for learning, given assistance by others. In addition, it has also been shown by Vygotsky that a child with a larger zone of proximal development will do much better in school than do others.

It seems to be likely that the idea of "the zone of proximal development" is relevant to group problem solving where one more experienced individual could move others forward in understanding increasing levels of abstractness.

2.5 Cognitive Theories of Learning

In cognitive models of learning, the learner is seen as an active processor of information and cognitive approaches to learning are more concerned with ways to help students become more effective processors of information. This is in marked contrast to the behaviourists' view, where they regard the learner as a passive recipient whose learning is automatically shaped by practice and reinforcement (Mayer, 1992). In fact, these two theories both have an important value in education.

Within a cognitive framework, the understanidng of learning has shifted gradually. Hamachek (1995) has provided a clear description about this evolution. Based on how animals learned, human learning was first seen as *response acquisition*. At this time, students were perceived as passive beings whose learning was influenced by the rewards and punishment which controlled and given by teachers. In 1950s and 1960s, a new view of learning emerged that of learning as *knowledge acquisition*. It emphasised how students acquired knowledge instead of focusing on students' responses to new information. Afterwards, because many educational psychologists began to do a large amount of research on how learning occurs in an actual classroom setting, the cognitive theory became matured in the 1970s and 1980s to its current status. The emphasis changed to *knowledge construction*, it concerns a person capable of controlling his or her own cognitive processes during learning. Learning is not merely responding to new information, nor is it just acquiring new information; it is also constructing new knowledge. Therefore, the most important teacher's responsibility is to help students to process new material in meaningful ways in order to encourage its storage in long-term memory.

There are three theorists who have been prominent in advancing the cognitive point of view: Jerome Bruner, David Ausubel, and Robert Gagne. The first two have a significant contribution understanding problem solving and are discussed briefly.

2.6 Jerome Bruner: Discovery Learning

Bruner's study integrates knowledge from biology, anthropology, linguistics, philosophy, and sociology. He views learning as involving three simultaneous processes: *(a) acquisition of new information; (b) transformation of knowledge; (c) check of the pertinence and adequacy of knowledge*. His research in the development of mind has been greatly influenced by Jean Piaget and Lev Semyonovich Vygotsky. However, he does not accept Piaget's idea of "stages" of human development. In an autobiography (Bruner, 1983), he stated:

> *"It never occurred to me to believe in stages of development in the Piagetian sense. There was always some way in which anything could be made clear to them, given patience, willing dialogue, and the power of metaphor."*

He took a different approach to cognitive psychology than that of Piaget. In his learning theory (Bruner, 1986), development of thinking was seen as a function of experience and apparently independent of maturational factors. The key concept was "representation". A person's representations collectively constitute that person's model of reality. There are three distinct modes of representation of reality: *enactive, iconic and symbolic*. The *enactive* mode of representation is highly manipulative in character. It consists of knowing some aspect of reality without the use of imagery, i.e. "knowing" how to do something (for example, a child knows how to ride a bike). In the *iconic* mode, the representation is based upon internal visual imagery that is governed by principles and techniques such as filling in, completing and extrapolating knowledge from available sensory experience to make transformations in perceptual organisation. As a person approaches adolescence, language becomes increasingly important as a medium of thought. The person thereby uses symbolic representations (mathematics and language) that are based upon an abstract and more flexible system of thought. A person will increase his or her knowledge and understanding by using these three modes together.

Bruner also places emphasis on the role of the teacher in learning. The role of the teacher is to help children to focus on the key concepts of what they are learning, and construct it in their own way. He treats discovery as it relates to a given culture and he prefers the term *problem solving* rather than *discovery* in discussions of creative learning (from "some elements of discovery", 1966). One major aspect of Bruner's contribution in the context of this project is the way individuals can be helped by others as they seek to find solutions to problems.

2.7 David Ausubel: Meaningful Learning

Ausubel has made a major contribution in learning, the main idea in his theory is the role of prior knowledge in learning. This idea can be seen in his early book that "*the most important factor influencing learning is the quantity, clarity and organisation of the learner's present knowledge*" (Ausubel, 1963). In the past, classroom learning can be located along two dimensions: *the rote-meaningful dimension and the reception-discovery dimension.* However, much confusion has been generated by regarding all reception learning as rote, and all discovery learning as meaningful. The clear distinction between these four kinds of learning was made by Ausubel (1978).

2.7.1 Reception and Discovery Learning

Reception and discovery learning are two quite different kinds of processes. In reception learning, the content of what is to be learned is presented to the learner, either by teachers or by written materials in its final form. All the learner has to do is to internalise or incorporate the content into his or her cognitive structure to learn and remember it. In fact, reception learning in schools is mainly associated with didactic forms of teaching (Ausubel and Robinson, 1969). Generally, the teacher presents the whole content to the students in some coherent form, thus the students do not need to engage in any real independent discovery learning. On the other hand, with discovery learning, the main content to be learned is not presented to the learner but must be discovered by the learner before it can be incorporated meaningfully into his or her cognitive structure. It means the learner has to undertake some kind of mental activity such as rearrangement, reorganisation or transformation of the given material to rebuild their cognitive structure.

Concerning the confusion which emerged between these two dimensions: *rote-meaningful and the reception-discovery*, Ausubel (1961) stated that both reception and discovery learning can be classified either as rote or as meaningful learning depending upon what happens after the content to be learned is presented to the learner (see figure 2.1).

As regards the relationship between discovery learning and problem solving, it was thought that discovery learning was a psychologically more involved process than reception learning, since the individual engages in a problem solving stage (Ausubel and Robinson, 1969).

2.7.2 Meaningful and Rote Learning

In Ausubel's view, the basis of meaningful learning is the quality and organisation of what the learner already knows. On the other hand, rote learning occurs if the learner lacks the relevant prior knowledge necessary for making the learning task meaningful. The following criteria were used to describe the circumstances thought most likely to produce rote learning (Ausubel and Robinson, 1969):

(1) the material to be learned lacks logical meaningfulness;

(2) the learner lacks the relevant ideas in his own cognitive structure;

(3) the individual lacks a meaningful learning set.

In summary, "*meaningful learning occurs when the learner's appropriate existing knowledge interacts with the new learning. Rote learning of the new knowledge occurs when no such interaction takes place*" (West and Fensham, 1974).

Ausubel believed that successful learning occurs when new material is linked with pre-existing knowledge and concepts, and is contrasted with "rote learning", which does not link new information to old cognitive structure and is therefore not made meaningful. He defined three important conditions which must exist before meaningful learning could take place (Ausubel and Robinson, 1969):

(1) the material itself must be relatable to some hypothetical, cognitive structure in a nonarbitrary and substantive fashion;

(2) the learner must process relevant ideas which relate to the material;

(3) the learner must process the intent to relate these ideas to cognitive structure in a nonarbitrary and substantive fashion.

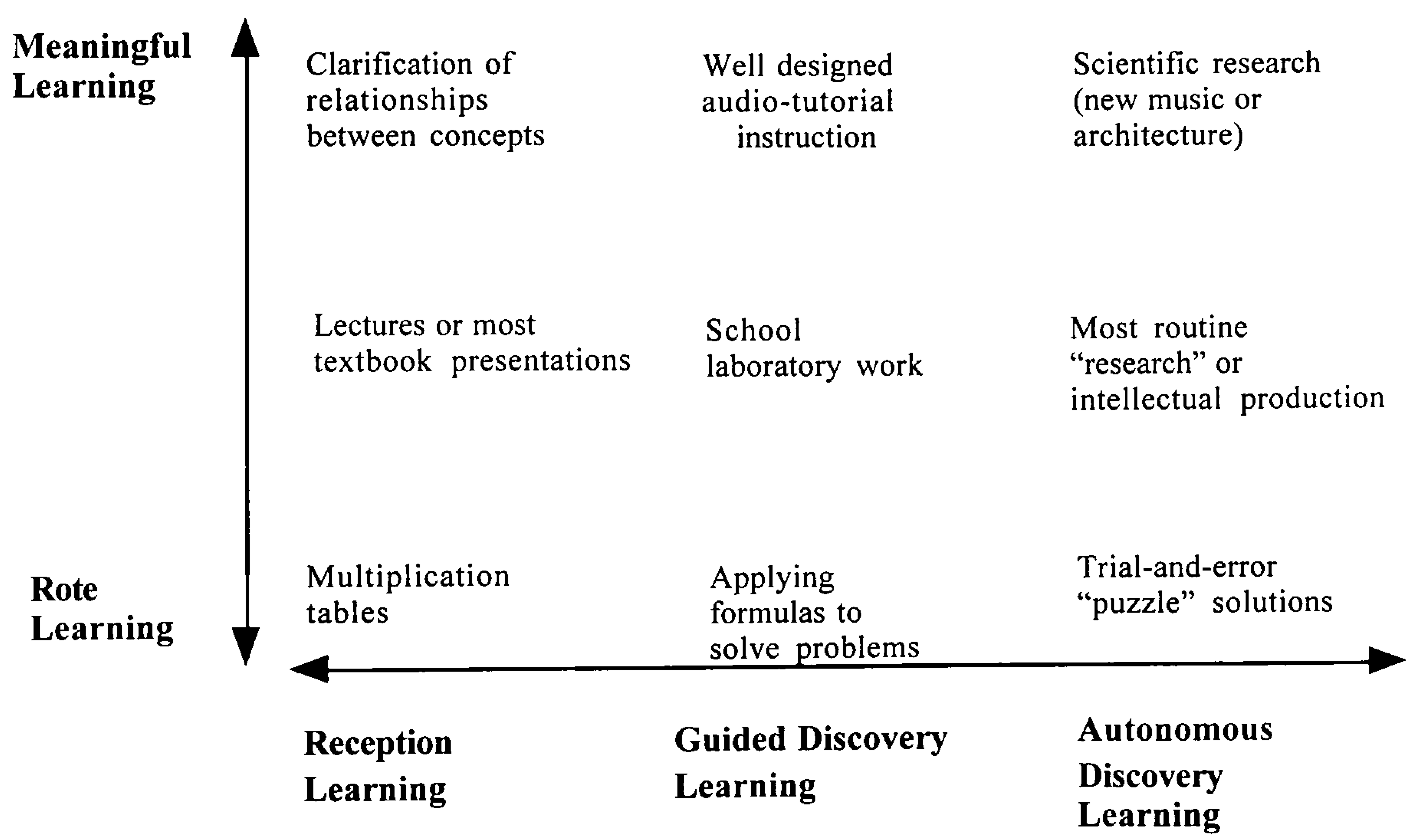

Figure 2.1 **Reception Learning and Discovery Learning (Ausubel, 1978)**

2.7.3 The Implication of Ausubel's Theory in Problem Solving

Ausubel suggested that previous knowledge and experience influenced future learning heavily. Although this contribution has been considerable in the context of classroom teaching, an important aspect does relate to problem solving. What the individual knows and how that information has been learned and is stored in his or her memory is likely to be critical in success in problem solving

2.8 Information Processing Models of Learning

The way that information is processed in learning has been summarised in the model proposed by Johnstone (Figure 2.2). In this, the learner is seen to view new events, observations and instructions through a perception filter which is influenced by what is already stored in the long term memory. In this way, the learner selects and interprets new information in terms of what he/she already knows.

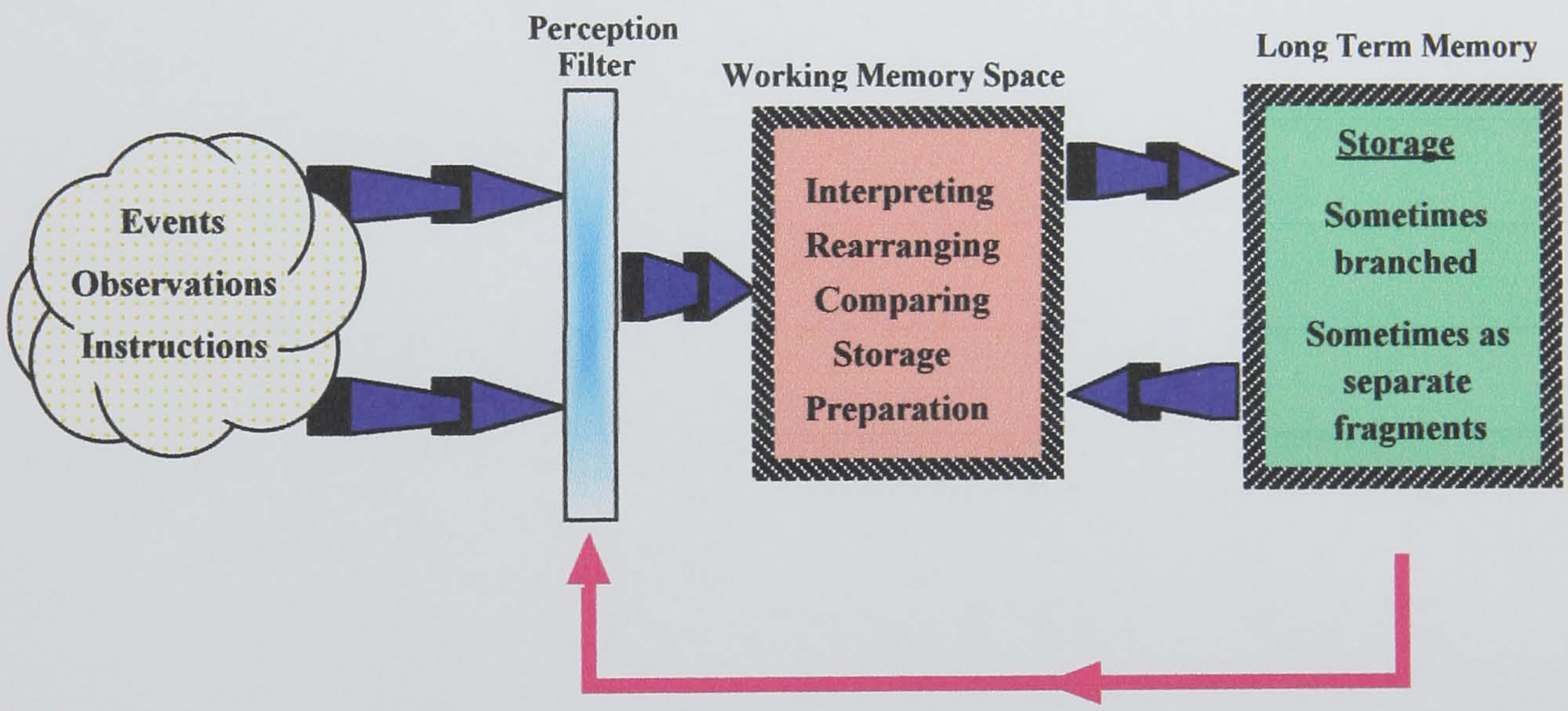

Figure 2.2 Information Processing Model (Johnstone, 1997)

The Working Memory Space is of limited capacity and is involved in holding new information, holding information which is moved from the long term memory store and processing information. In problem solving, new information and the nature of the problem have to be taken into the working memory space and the selection of what is taken in is influenced by what is already held in the long term memory. Clearly, if a pupil is trying to solve a problem on an individual basis, then the capacity of the working memory (thought to grow on average by 1 unit for each two years of age to be 7 ± 2 in an adult (Miller, 1956) may be a limiting stage. It has to be noted that Miller measured working memory space by recall tests without information processing. However, if pupils attempt to solve problems in groups, then the limitations of the working memory space may be unimportant.

What is stored in the long term memory and how it is stored will only effect the way the perception filter operates but will also influence what is transferred into the working memory space in an attempt to solve a problem. This will be important both for individual problem solving and group problem solving although, in the latter case, pupils will be able to influence each other in that it is unlikely that all member of a group will hold the same information in the same way in long term memory. It is hoped that this interchange of experience will reveal something of the way the long term memory influences success in problem solving.

Chapter Three

Problem Solving

In the last chapter, specific contributions in understanding problem solving from some learning models were discussed. Over the years, a huge literature has developed which focusses on problem solving. In this chapter, some of this literature is reviewed, with an emphasis on those contributions which are seen to be more directly related to problem solving in the sciences in general and chemistry in particular. In this, it has to emphasised that the focus of this project is on open-ended types of problems while much previous research has considered those types of problems that can be described as exercises or applications of algorithms.

3.1 The Developmental Theory of Problem Solving

Early experimental problem-solving tasks were mainly "content free". Most of them seem to be "gamelike" and people obtained the solution without specialised knowledge. At that time, a number of General Problem-Solving Strategies (GPS) such as means-ends analysis, hill climbing and working backward etc. appeared to be taught to students. GPS was employed in specific subject domains such as physics and mathematics. Simultaneously, cognitive psychology developed a new direction about problem solving.

Polya (1945) proposed a model of problem solving that consists of four steps:

(1) *Understand the problem;*
(2) *Devise a plan;*
(3) *Carry out the plan;*
(4) *Look back.*

The initiation of the model is based on solving mathematics problems and it may be suitable for a routine exercise but is not a model of the way people usually solve real problems.

A major advance for investigating problem solving came from cognitive psychology. The information processing theory of human problem solving, initiated by Newell and Simon (1972), characterised problem solving as an interaction between the task environment and the problem solver. They saw the solver as an Information-Processing System and the properties of the Information-Processing System such as the capacity of working memory and retrieval processes in long-term memory were considered to influence problem-solving outcomes.

This kind of thinking arises naturally from the Information Processing Model (figure 2 of chapter 2). Indeed, this model suggests some of the key features of mental activity that might be the limiting factors in problem solving ability. Of these, two are particularly important. The limited capacity of the working memory space (where the actual process of problem solving is occurring) may be a significant factor in that, if the process of problem solving involves too much space (in terms of "chunks" of information or processing), then problem solving may be impossible. However, if writing and talking with others is possible, then the effect of this limited capacity may be minimised. Secondly, the vital importance of previously held knowledge can be seen. This can influenced the way the problem solver actually "sees" the problem as well as the way such knowledge can be used to solve the problem.

3.2 The Factors Influencing Success in Problem Solving

Gabel and Bunce (1994), in their review of research studies on problem solving in chemistry for the past 12 years, proposed that students' success in problem solving appear to be influenced by three factors. These factors are:

(1) *The nature of the problem and the underlying concepts on which the problem is based*: it includes the problem style and conceptual understanding.

(2) *Learner characteristics*: it includes the individuals' cognitive styles, developmental levels and their knowledge base.

(3) *Learning environment factors*: it includes problem-solving strategies/ methods, individual or group activity.

To clarify the factors that influence successful problem solving, this project considered Gabel and Bunce's suggestions and tries to build up a broader view of problem solving in chemistry. In this chapter, what appear to be the most important groups of factors that would influence pupils' success on problem solving are discussed. The first group is prior experiences that include prior knowledge base and the emotional experience. The next group is the effects of cooperative group work. The third group is problem solving strategies/ methods, including algorithms, conceptual understanding and problem solving skills. The fourth group covers the factors that arise from the Information-Processing Model. The fifth group is the individual's cognitive styles, developmental levels and other factors. Finally, it is important and necessary to take account of the possibility of teaching problem solving.

3.3 Prior Experiences and Successful Problem Solving

Prior problem solving experience has been shown by several studies to be important in determining successful problem solving (Ashmore *et al.*, 1978; Frazer and Sleet, 1984;

Waddling, 1988). The prior experiences include prior knowledge and emotional experience related to the problem solving area. These researchers all employed a network to explore the influence of prior experience on chemistry problem solving.

Firstly, Ashmore, Frazer and Casey (1979) proposed a problem-solving network approach to show the interconnection of pieces of information and to identify all the information required to solve problems. The networks were derived from breaking down problems into unitary pieces of information and reassembling them to arrive at a solution. The information appearing in the networks were from three areas: it might be stated in the problem, or retrieved from pupils' memory, or by reasoning. They suggested that the network approach could help a teacher to perceive student difficulties in solving problems. Waddling's study (1988) confirmed that the problem-solving network designed by students can help teachers understanding the students' thinking patterns. The networks revealed the factors which prevented the students from problem solving successfully. Ashmore *et al. (1978)* finally concluded that the best chances for success in chemical problem solving rest on a combination of (a) a strong background knowledge of chemistry; (b) a knowledge of problem solving strategies and tactics; (c) confidence.

A similar study by Frazer and Sleet (1984) used a closed chemistry problem which involving calculations and broke the problem into a series of sub-problems to identify and ascertain why some students, who can separately solve all the sub-problems, but are still unable to solve the complete problem. They employed the same network method in accordance with Ashmore *et al.*'s approach. The results showed that many of the students who cannot solve a main problem but who are able to solve all its sub-problems lack a clearly defined plan for solving the problem. It might be due to their lack of confidence or they become uncertain or confused when they encountered an unfamiliar term, or when confronted with an unusually long problem. These experiences of uncertainty may put an excessive burden on their working memory capacities and prevent them from recognising all the steps in the main problem. It is clear that students' emotional experiences are definitely involved in the process of problem solving. Although it is a closed problem, the network approach and the prior experiences seem also to be relevant in the open-ended problem.

In Gayford's study (1989), an interesting finding indicated that pupils came to problem-solving activities with their own experiences and background knowledge that may or may not have been derived from school. For instance, many pupils' previous knowledge about enzymes and water loss from the leaves of plants was gained from television, books and their own observations in the environment and this inevitably affected their performance in the task.

In a case study of a college chemistry student conducted by Herron and Greenbowe

(1986), the student lacked the ability of verification (the ability to see if the answer obtained is reasonable) failed to solve the chemistry problem. She had difficulty when *"she was confronted with unfamiliar problems that require analysis of the problem to produce a sensible representation and subsequent use of familiar rules in a new context"*. She was described as a "*rule learner*": she could apply rules correctly but was unable to solve problems that required the integration of algebra, chemistry and reasoning. In conclusion, the authors pointed out that successful problem solvers exhibit four kinds of characteristics:

(1) Have a good command of basic facts and principles.

(2) Are able to construct appropriate representations of problems.

(3) Have the ability to use general reasoning strategies that permit logical connections among elements of the problem.

(4) Are able to apply several verification strategies to insure the problem representation is consistent with the given facts, the solution is logically sound, the computations are checked for errors, and the problem solved is the problem presented.

3.3.1 Prior Knowledge Base and Problem Solving

Frazer (1982) reviewed a sequence of chemical problem solving research papers. Not surprisingly, he drew a clear conclusion that chemical problem solving requires chemical knowledge. However, much work has indicated that students failed to solve problems, even though they possessed most of the requisite conceptual knowledge (Sumfleth, 1988; Shaibu, 1992; Adigwe, 1993; Lee, 1996).

Sumfleth (1988) administered three tests, which included an explanation test, an achievement test and a connectivity test, with students aged 16+ years and focused on two areas of chemistry: structure-property relations and the setting-up of formulae. The results showed that the students had a basic knowledge of chemical terms but did not recognise relationships and were unable to apply their knowledge. It was concluded that the knowledge of terms is a necessary, but not sufficient, prerequisite for successful problem solving. Shaibu (1992) used structured paper-and pencil tests in mechanistic organic chemistry to identify the relationship between the conceptual knowledge of science students and their ability to use such knowledge to solve contextual problems. It was found out that students failed to solve the problems, even though they possessed most of the requisite conceptual knowledge. There was a weak link between the students' possession of requisite conceptual knowledge and their problem-solving proficiency.

In an large study, Adigwe (1993) employed five tests to identify some correlates of students' performances in chemical problem-solving of an algorithmic nature at the

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In an large study, Adigwe (1993) employed five tests to identify some correlates of students' performances in chemical problem-solving of an algorithmic nature at the

secondary school level. Four factors [attitude, logical thinking ability (proportional reasoning ability), knowledge of chemistry, and knowledge of mathematics] were considered to play some role in problem solving in this study. These five tests are described as below:

(1) *A free response achievement test (FRT): to assess the students' capabilities to solve chemical problems on stoichiometry.*

(2) *A structured response test (SRT): to assess the students' knowledge of the relevant chemistry.*

(3) *A mathematics test (MST): to assess the students' knowledge of the relevant mathematical operation.*

(4) *Attitude test (ATQ): to assess the students' attitudes towards chemical problem-solving.*

(5) *A modified version of the Group Test of Logical Thinking (GTLT): to assess the students' capabilities to do proportional reasoning.*

The results indicated that the students' logical thinking ability and knowledge of mathematics appeared to be the crucial variables in chemical problem solving. The author stated that, although the significant relationships of the relevant knowledge to performances in problem solving have been proved, it does not guarantee that the knowledge of the domain alone could lead to successful problem solving. The procedural knowledge and the reasoning skills that go with it are also important factors. He also suggested that the students must have acquired logical thinking ability and the capability for basic mathematical operations before they are introduced to stoichiometry. However, although logical thinking ability and the capability for basic mathematical operations played an important role is suitable for stoichiometry problems, it does not mean it could be applied to other non-mathematics problems.

3.3.2 Knowledge, Learning and Problem Solving

Science is hard to learn. Johnstone (1991) suggested that chemistry, physics and biology each contain at least three levels of knowledge: the macroscopic, the microscopic and the symbolic level. It is hard for pupils to learn if they have to learn these three aspects of knowledge simultaneously. Past research studies indicates that students have great difficulty with the microscopic level and develop many scientific misconception (Nakhleh, 1992; Garnett *et al.* 1995). This may have significance in problem solving in chemistry in that, if a problem requires confidence in moving between all three levels, then a source of difficulty has been introduced at the outset which hinders successful problem solving.

Chandran *et al.*(1987) examined the role of four cognitive factors, which are formal reasoning ability, prior knowledge, field dependence / independence and memory capacity, on chemistry achievement of Australia grade 11 students. The results indicated that prior knowledge and formal reasoning ability were both significantly related to chemistry achievement. Interestingly, they found that field dependence / independence and memory capacity played no significant role in chemistry achievement. The failure to observe any effect arising from field dependence / independence might be affected by the sample used, the chemistry tasks and/or the measurements made. However, the finding that prior knowledge is a significant predictor of achievement in chemistry is consistent with Ausubel's (1978) meaningful learning theory.

In looking at problem solving in chemistry, it is easy to appreciate that a lack of appropriate chemical knowledge will hinder problem solving ability. Lychcott (1990) studied high school chemistry students as they solve problems about mass in chemical reactions. The evidence revealed that students who solved simple mass-mass problems correctly had woefully inadequate chemical knowledge. He concluded that most chemistry students when faced with an unusual or more difficult problem could be expected to fail if chemistry instruction did not provide a set of rules to follow or did not help them understand chemical knowledge during the learning process. If we want our students to be able to solve problems, it is essential to help them to understand requisite knowledge and avoid just simply possess this knowledge in a rote fashion. In addition, Anderson (1993) also suggested that bringing together ideas from problem-solving theory and learning theory can make important progress with respect to understanding how complex problem-solving skills are learned.

Bodner (1991) examined the conceptual knowledge that chemistry students construct during their undergraduate experience. The study has yielded some conclusions:

(1) *knowledge is constructed in the mind of the learners (Bodner, 1986). During the learning process, students construct their knowledge but have difficulty in applying it to other areas;*

(2) *misconceptions are resistant to instruction;*

(3) *knowledge is not the same as understanding. Students all too often possess knowledge without understanding. It was revealed that the same problem may be solved in varying ways by different individuals due to dissimilar problem solving steps, strategies, and knowledge.*

3.3.3 The Cognitive Structure

The cognitive structure existing in pupils' mind has been considered by many researchers as an important factor which affects problem solving (Kempa and Nicholls, 1983; Lee, 1985; Lee *et.al.* 1996). According to Ausubel's learning theory, meaningful learning involves effective linking between new knowledge and existing cognitive structure (Ausubel *et.al.*, 1978). Three aspects of linkage are important in learning processes in science.

In an important study, Kempa and Nicholls (1983) used chemistry achievement test and word association test to explore the relationship between students' cognitive structure and their problem-solving abilities in the context of chemistry. The term "*cognitive structure*" was defined in terms of their ability to solve problems in a particular concept area. They found that the cognitive structures of good problem-solvers are more complex and contain more associations than those of poor problem-solvers. The strength of links between different concepts seems important in determining problem-solving behaviour. It was also revealed that the deficiencies in the cognitive structures of poor problem-solvers appear predominantly for abstract concepts. Although this study used problems mainly of an exercise or algorithmic nature, its findings may also apply in more ended problems.

3.4 The Effects of Cooperative Group Work on Problem Solving

Problem solving is typically not a solitary activity. In our society most problem solving happen in groups, such as work teams, families and friendship groups. Problem solving is an inherently cooperative process in which several individuals join together to accomplish shared goals (Johnson and Johnson, 1975). Thus, if students want to become successful problem solvers, it is necessary that they must learn how to cooperate with their partner: talking together and sharing information, exchanging each other's experience and generating inferences about data.

The small cooperative group was described by Slavin (1983) as an instructional environment in which individual and group incentives are used to promote student engagement in tasks to increase helping behaviours among group members. Several studies have examined the effects of cooperative group work on science achievement and learning (Basili and Sanford, 1991; Grant, 1978; Foster, 1981; Kempa and Ayob, 1991, 1995; Tingle and Good, 1990). Before reviewing these studies, it is important to look at the results of an investigation by Qin and Johnson (1995). This provides a broader view of cooperative group work in problem solving.

Qin and Johnson (1995) examined 46 studies that were published between 1929 and 1993 to determine the relative impact of cooperative and competitive efforts on problem solving success. They considered six independent variables during their investigation, which include:

- *(1) cooperation versus competition;*
- *(2) the type of problem solving tasks that include linguistic, nonlinguistic, well-defined, and ill-defined problem;*
- *(3) the age of participant;*
- *(4) the year of publication;*

(5) *the duration of research study;*
(6) *methodological quality of study.*

There are 63 relevant findings listed in their review and clear evidence showed that cooperation promoted greater success with nonlinguistic problems than did competition. One area is to look at the internal dynamics of groups working on nonlinguistic problems. According to the results of their investigation, Qin and Johnson pointed out that only Lovelace and McKnight's (1980) study found that cooperative groups generated more strategies for solving the problems than did competitors working alone. Nevertheless, the nonlinguistic problems were mostly mathematical in nature and it is not certain if their findings can be generalised to other types of problems.

If the nonlinguistic problems are not mathematics and close to conceptual tasks, are the cooperative efforts still effective? Basili and Sanford (1991) investigated the conceptual change of college chemistry students in small cooperative groups. The results provided evidence that cooperative group work on a concept-focused task can provide a viable environment for learners to overcome misconceptions in chemistry. It also revealed that group discussion could help students clarify their views of science and help them to develop explicit distinctions between everyday and scientific words. Overall, the cooperative approach is effective in both mathematical and conceptual problems.

Referring to the ill-defined problem, Qin and Johnson (1995) said that solving in an ill-defined problem requires generating a creative or novel representation and procedure primarily through imagery. The evidence indicated that cooperative efforts resulted in better performance in these ill-defined problems. This may be due to individuals exchanging ideas and building a shared representation of the problem through group discussion.

In general, the past work has so far yielded positive results that cooperative group work produces higher quality problem solving on a wide variety of problems that require different cognitive processes to solve. The possible reasons why cooperation may increase problem-solving success include sharing expertise and insights among cooperators, the generation of a variety of strategies to solve the problem, increased ability to translate the problem statement into questions, the development of a shared cognitive representation of the problem. Additionally, Tingle and Good's (1990) study of 178 high school students in chemistry provided further evidence that, in most cases, pupils were able to teach their members by modelling, asking questions, and using analogies during group discussion. This may increase problem-solving success.

Finally, it is important to ask whether age is a factor in enabling cooperative group work to be successful. Qin and Johnson (1995) concluded that the difference between cooperative efforts and competitive efforts on problem solving would be greater for older participants than for younger participants. It is may because the problem solving is complex and often requires the higher-level reasoning: age and experience play a vital role that could affect the ability of reasoning and group interactions.

There is general agreement from many studies that cooperative groups indeed increase problem-solving success. Nevertheless, it is still unclear how the internal dynamics determining cooperative group approach problems. In addition, other factors may also influence the effectiveness of cooperation, such as the leadership of group, the pupils learning style and developmental level. For instance, Basili and Sanford (1991) found out that poor leaders prevented effective discussion by rushing through questions and imposing their narrow view of the purpose of the task. In this project, the researcher have tried to encourage pupils to discuss frequently to avoid the poor leader effect.

3.5 Algorithms and Conceptual Understanding

It is clear that students do not always use algorithms to solve problem and, more often, they need the other skills to reach a solution. As regards the role of algorithms in problem solving, Bodner (1987) pointed out that algorithms are useful for solving routine questions or exercises but not sufficient for answering exam questions that are more likely to be problems for students. He insisted that there is more to working problems than just applying algorithms in the correct order. On the other hand, Frank, Baker, and Herron (1987) argued that algorithms are not necessarily bad and some of them are useful shortcuts for exercises. However, algorithms may actually prevent understanding when students encounter a real problem. Much depends on how the algorithms are used by students. They suggested that, if a student is able to modify an algorithm or create a new algorithm, then he or she is making use of algorithms as an efficient tool for unlocking problems. Therefore, it is necessary to help students to use algorithms. How to do this is much less clear.

Numerous studies have shown that strict adherence to instruction that emphasises algorithmic problem solving in chemistry does not produce conceptual understanding in students (Nurrenbern and Pickering, 1987; Sawrey, 1990; Pickering, 1990; Nakhleh, 1993; Nakhleh and Mitchell, 1993).

Nurrenbern and Pickering (1987) examined how the students do both a traditional problem on gases and a multiple-choice question that had no mathematical content but asked for a purely conceptual understanding of gases. The results revealed that students can solve problems about gases without knowing anything much about the nature of a gas, and they can solve limiting-reagent problems without understanding the nature of chemical change. They found little connection between solving an algorithmically-based problem and understanding the chemical concept behind that problem. Sawrey (1990) repeated the Nurrenbern and Pickering's experiment with a larger, more uniform group of students at a well-known university. A similar finding appeared with even the good performers still having difficulty with the concept questions. It confirmed the experimental results from Nurrenbern and Pickering with a very different student population.

Another study by Pickering (1990) also replicated the work of Nurrenbern and Pickering. He used a conceptual gas question and a traditional gas question to examine whether the ability to do the conceptual questions was due to some special ability or due to specific knowledge. The students who enrolled in the freshman chemistry course and followed into organic chemistry course participated in the research. He concluded that the difficulty with the conceptual question is the lack of some specific factual knowledge about gases, not some special ability difference The results also showed that the students who can successfully solve both gas questions performed slightly better on the organic final exam.

Nakhleh (1993) constructed five pairs of questions in five specific areas of general chemistry [*(1) ideal gas laws; (2) equations; (3) limiting reagents; (4) empirical formulas; (5) density]* to test the differential performance on conceptual and problem-solving question. Approximately 1000 first-year students were involved in the study in four courses: *remedial, science/engineering major, chemistry major, and honours*. The questions on the ideal gas laws were adapted from studies by Nurrenbern and Pickering (1987, 1990) and Sawrey (1990). The result showed that 85% of the students (N=1090) could successfully answer the algorithmic gas law question, but only 49% could correctly answer its conceptual counterpart. As with Nurrenbern and Pickering's study, it was concluded that, across all levels of student, conceptual problem-solving ability lagged far behind algorithmic problem-solving ability. Many students can answer an algorithmic question about a chemical idea but cannot answer a conceptual question dealing with the same idea.

Nakhleh and Mitchell (1993) conducted a similar study that involved 60 freshman chemistry students and was completed in two parts. The first part used paired exam questions on gas laws, one a conceptual question and the other an algorithmic question, to identify students as being either conceptual or algorithmic problem solvers. The second part interviewed six students who were specifically selected, each student worked out the same two questions and an additional pair of stoichiometry questions by verbalisation. The results of first part showed that more than 50% of students fall in the low conceptual category while 85% of students are good algorithmic problem solver. The conclusion is that solving problems using algorithms does not seem to facilitate understanding of the underlying concept. The interviews' results indicated that all six students answered both gas law problems correctly, but most of them used algorithms to solve conceptually based problems regardless of their conceptual problem-solving ability. That is, most students rely on algorithms to solve problems, even problems specially intended for conceptual solution. The authors finally reaffirmed that current algorithm-based teaching does not necessarily lead to conceptual learning.

3.6 General Problem-Solving Strategies and Problem Solving Skills

Successful problem solvers exhibited more effective problem solving skills such as organisation, persistence, evaluation, heuristics and formal operations than unsuccessful problem solver (Greenbowe, 1983). In spite of these skills, it has been noted that the skill of representation is important for solving some difficult problems (Bodner and Domin, 2000; Greenbowe, 1983).

When students work on a problem, the first step is to find and understand the problem. If they do not understand a problem at the beginning, it is impossible for them to solve the problem successfully. Many activities such as imaging, inferencing, decision-making and retrieving of knowledge from memory frequently have been used to help students understanding the problem. As Haye (1981) explained, there are two types of representations which can exist when people try to understand the problem. First, there is the internal representation that reflects how people imagine the objects and relations in his or her mind. The term "internal representation" has also been defined as "*information that has been encoded, modified, and stored in the brain*" (Simon, 1978). Another is external representation: people will create it by drawing sketches or diagrams, or writing down symbols or equations. To clearly distinguish between internal and external representations, Bodner and Domin (2000) defined the internal representation as "*the way in which the problem solver stores the internal components of the problem in his or her mind*". As to external representation, they defined it as "*physical manifestations of this information*". It may be a sequence of words used to describe an internal representation, a drawing, or a list of information that captures particular elements of an internal representation, or an equation such as PV= nRT.

For some difficult problems, an external representation is very helpful. Bodner and Domin's (2000) recent study at university chemistry student level provided significant evidence. For instance, when students tried to balance the following equation:

$$I_3^- (aq) \quad + \quad S_2O_3^{2-} (aq) \longrightarrow I^- (aq) \quad + \quad S_4O_6^{2-} (aq)$$

By using the Lewis structure, students were able to understand how Lewis structures can be used to explain the products of this reaction. In addition, students are more successful balancing redox equation by using this approach. They concluded that one of the characteristic differences between successful and unsuccessful problem solvers is the number and kinds of representations brought to the problem. It is possible that student performance on problem-solving tasks improves when adding a symbolic representation or drawing a diagram, as Bodner and Domin's claim, but will this be as effective and significant for secondary school pupils as it is for university students? In fact, most school pupils do not appear to know how to use drawing or other representations to help themselves understand a difficult chemistry problem at all.

Greenbowe (1983) investigated the variables involved in chemistry problem solving. Thirty college chemistry students and one college chemistry professor solved chemical stoichiometry problems. He found that successful problem solvers were able to construct and use an appropriate representation for the problems and their conceptual understanding influenced the problem representation. It is obvious that conceptual understanding and representation are reciprocal causation. The stoichiometry problems have been identified as being very difficult for most school pupils. In the light of difficulty, it seems to be practical to use an appropriate representation to solve some kind of difficult problems. Therefore, if teachers want pupils to be able to solve these difficult problems, they might find it is helpful to place emphasis on representation skills.

3.7 The Role of Long Term Memory in Problem Solving

Student may learn and understand many science concepts from science courses. Therefore, it does not guarantee that they will solve problems successfully. Many factors may influence the success in problem solving and are discussed at previous sections, such as working memory overload which has been discussed previously. Here, it is essential to examine the role of long term memory in problem solving. In their literature review, Gabel and Bunce (1994) suggested that "how science concepts are networked in long-term memory, and the ease of transferability to working memory are important conditions leading to success or failure in problem solving". This is consistent with the arguments put forward by Ausubel (1978) and is implied explicitly by the Information Processing Model (see 2.8). It is also supported by the work of Kempa and Nichols (1983).

If school pupils are to be able to solve open ended problems in chemistry, they will require the necessary chemical knowledge in long term memory. However, how that knowledge is stored and linked will also be important. Chemical knowledge acquired in one context may well not be easily accessible to be applied in a different context while one concept may not be well linked to another, making their meaningful use in problem solving difficult.

3.8 Cognitive Style and Problem Solving in Science Education

A series of studies of chemistry problem solving by Niaz (1987, 1988a, 1988b, 1988c, 1989) included that not only working-memory capacity as an important variable but also students' cognitive styles and formal-operational reasoning patterns.

In science education, the cognitive variable described as Field Independence (FI) / field Dependence (FD) is regarded as the most important cognitive style. A person who is field independent is able to distinguish the key message from the surrounding information while the filed dependent person cannot do this so easily. Several studies have looked at this variable in relation to problem solving. Four research investigations (Ronning, McCurdy and Ballinger, 1984; Pirkle and Pallrand, 1988; Lawson and Wollman, 1977; Squires, 1977) all focused on the field independence / field dependence within science. These studies were examined by Helgeson (1994) collectively and the evidence from those studies clearly indicated that high school students who are field-independent enjoy a significant advantage over field-dependent students in solving science problems.

Since many researches in problem solving focused on problem-solving methods/strategies and domain specific knowledge, Ronning, McCurdy and Ballinger (1984) proposed that a viable theory of problem solving should consider a third component of problem solving: "*individual differences*". They adopted the cognitive style as being a 'useful indicator' and chose the well-known field-independence / field-dependence as the main factor. After detailed analyses, they found those field-dependent students responded more briefly, there being more pauses and false starts than did the field-independent students. On the other hand, field-independent students were more likely to attack the problems by keying on relevant information and they significantly out-performed field-dependent students on the problems.

3.9 Problem Solving and Teaching

There are important questions to be posed: Why teach problem solving? Can problem solving be taught? If so, how can problem solving be taught? It appears from a number of studies that teachers do believe that problem solving skills can be taught. There is, however, scant evidence that such skills can be transferred from one context to another.

It has been shown that there is a gap between conceptual understanding and algorithmic problem solving in chemistry students from high school to graduate school (Nakhleh, 1993; Bunce and Gabel, 1991; Osborne and Cosgrove, 1983; Bodner, 1991). It might be caused by the conventional teaching that always focusses on correct numerical answer. There have been several studies providing some insights into the question (Phelps, 1996;

Gayford, 1989).

Phelps (1996) tried to bridge the gap by altering the instructional method in general chemistry and implementing it in science major and non-science major university students. The approach he used focussed on conceptual problem solving and the problem rarely had a numerical answer. The many positive results obtained indicated that the nonscience majors' students showed more enthusiasm for the course and were less resistant to chemistry and more involved in the course. The science majors' students were insecure because this approach was not consistent with their expectation of the nature of chemistry. According to their prior experience, they believed that chemistry problems had to have a right answer and that they should know it. However, after adjusting their expectations, many science majors students appreciated spending more time developing the concepts.

It would appear that it is possible to change the instruction method and to adjust student expectations, with outcomes that students are able to change their strategies. It seems clear that if the goal of chemistry instruction is to have students think about and solve conceptual problems as well as algorithmic problems then the approach to chemistry instruction must change (Nakhleh and Mitchell, 1993). Two open-ended biology problem tasks were used in Gayford's study (1989), he suggested that a logical approach to problem solving could form the basis of a model for teaching and assessment of group performance in science.

In Tingle and Good's (1990) study, they suggested that cooperative grouping is a viable alternative strategy for chemistry problem solving. The cooperative group could provide an active environment for students to practice solving problem rather than through reception learning. If a teachers want to teach their pupils about problem solving skills, it is feasible by using cooperative groups to enhance students' problem-solving ability. Gabel and Sherwood (1983) used four strategies to teach solving the mole concept, the gas laws, stoichiometry and molarity problems.

Overall, the evidence from the work discussed suggests that, in a given context, pupils and students can be given assistance in developing strategies in solving problems. However, much of this may well be a matter of practice as they gain confidence in the application of appropriate methods and algorithms. It is much less clear if pupils and students can be taught how to solve open ended problems. However, it may be that practice in such problems raises levels of confidence and generates a willingness to take risks in seeking solutions.

Chapter Four

The Development of Problem Solving Exercises

While it has been established that the skill of problem solving has received a high profile in Scottish education as well as in other systems, it has also been noted that the type of problems that are usually under consideration are those which could be described as algorithms. In life, however, problems tend to be much more open-ended, less quantitative and less well defined.

To explore how pupils approach problems in chemistry that are not algorithmic in nature, it is necessary to develop a set of problems that could be used with school pupils and which would allow exploration of the processes of problem solving.

4.1 The Criteria

In designing these problem solving exercises, many factors must be considered. First, the topics of the problems had to reflect the themes and objectives which are involved in the secondary school chemistry curriculum. There is no national curriculum in Scotland (Clark and Munn, 1997). Post-fourteen-year-old pupils in Scotland take courses leading to awards in the Scottish Certificate of Education (SCE) at Standard Grade and Higher Grade. Therefore, the Standard Grade syllabus was employed to define the areas of chemistry used in the problem solving exercises. The Standard Grade Arrangements in Chemistry (1997) consists of fifteen topics listed as below.

1. *Chemical Reactions*
2. *Speed of Reactions*
3. *Atoms and the Periodic Table*
4. *How Atoms Combine*
5. *Fuels*
6. *Structure and Reactions of Hydrocarbons*
7. *Properties of Substances*
8. *Acids and Alkalis*
9. *Reactions of Acids*
10. *Making Electricity*
11. *Metals*
12. *Corrosion*
13. *Plastics and Synthetic Fibres*
14. *Fertilisers*
15. *Carbohydrates and Related Substances*

In the Standard Grade examinations, there are two levels offered: General Chemistry and Credit Chemistry. A survey of past papers at both levels from 1992 to 1997 showed two kinds of question: knowledge and understanding; problem solving. The questions in the latter group were largely opportunities for pupils to demonstrate applications of knowledge and were not open-ended in any way. Thus, in developing a set of problems to explore the process of problem solving, this type of question was rejected. Instead, problems were developed that were more open-ended.

Open-ended problems tend to be those most frequently encountered in life. Several studies concluded that it is important that students are enabled to apply scientific knowledge to their real-life problems and issues. Hence, the research also considered societal issues and real-life problems as factors in deciding which subjects would be chosen.

Problem solving very often involves experimental work but it is not always so. In fact, problems can be tackled on paper, by discussion in a group, or even by an individual just thinking in a disciplined way. The chemistry problems devised in this project were simply paper-and-pencil activities and did not involve any practical activity. Part of the reason lay in the enormous difficulty in controlling variables in laboratory problems.

A set of eighteen chemistry problems was devised. The set of eighteen units covered many areas of the Standard Grade syllabus and reflected a variety of approaches and styles. These were based on the Standard Grade Chemistry syllabus although some of them, in terms of difficulty, were thought to be more appropriate for pupils studying for the Higher Grade. The eighteen chemistry problems were categorised according to the eight types of problems which are set out by Johnstone and introduced in chapter 1.3. Types 1 and 2 problems are mostly related to algorithms and recall knowledge. Type 3 - 6 are more complex; among these types of problem, one of the variables (data, method, goal) is not fully specified. Types 7 and 8 seem to be more like real life problems and have been found to be very hard to design. Therefore, this project put much emphasis on problems of types 3, 4, 5, and 6.

This project planned to use the problems with groups of three in the hope that these interactions would provide evidence about how the problems were being solved. The problems were deliberately designed to be difficult so that they could not be satisfactorily solved by the pupils just recalling factual information learned by rote without understanding. Pupils within the groups would be encouraged to work together. The desired level of difficulty in the problems was that a pupil was unlikely to be able to solve it on his or her own. They needed to work in small teams, helping each other.

It is possible to think of an individual pupil interacting with a problem in the following way (Figure 4.1):

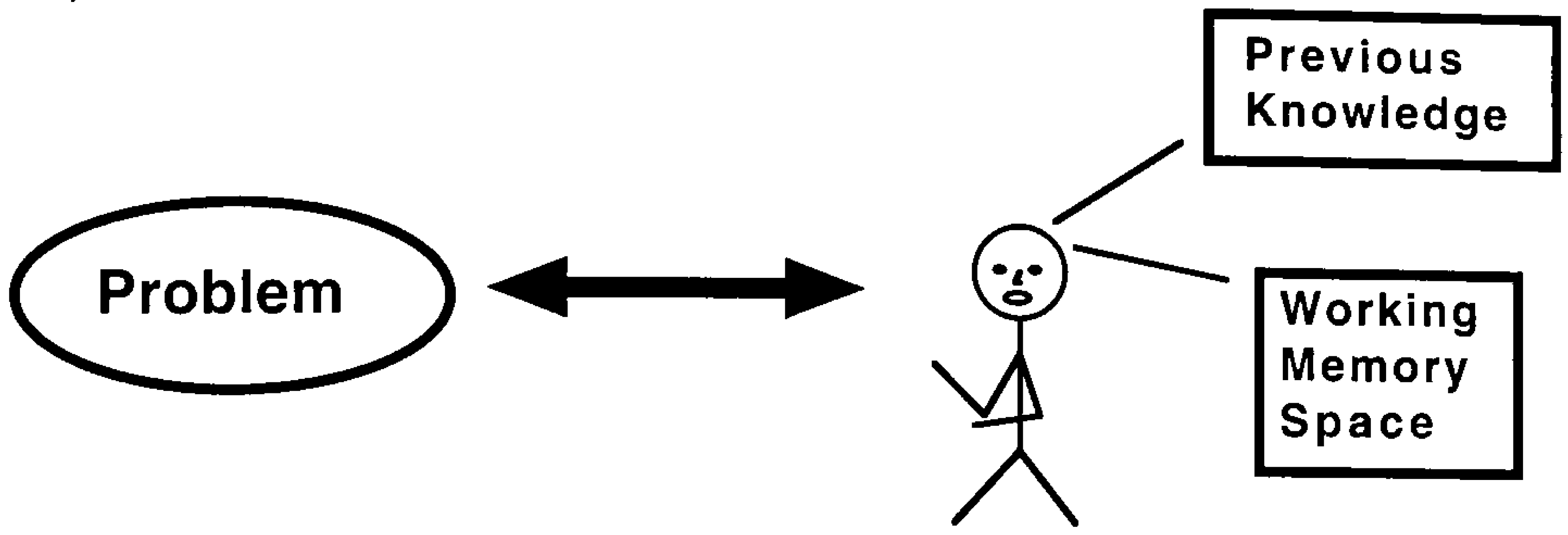


Figure 4.1 Problem Solving by Individual

The only way that a pupil can solve the problem is to use his or her own previous knowledge and working memory space. If the pupil does not have sufficient previous knowledge or his or her working memory space was overloaded, he or she might not be able to solve the problem successfully.

Working in groups of three, one of the advantages is that they can combine their previous knowledge and working memory space together to reduce the difficulties. In addition, more importantly, like one of Grant's (1978) research conclusions that "group work can improve the quality of pupils responses to problems that require the ability to think". The following diagram (Figure 4.2) illustrates the way that the problem solving might occur.

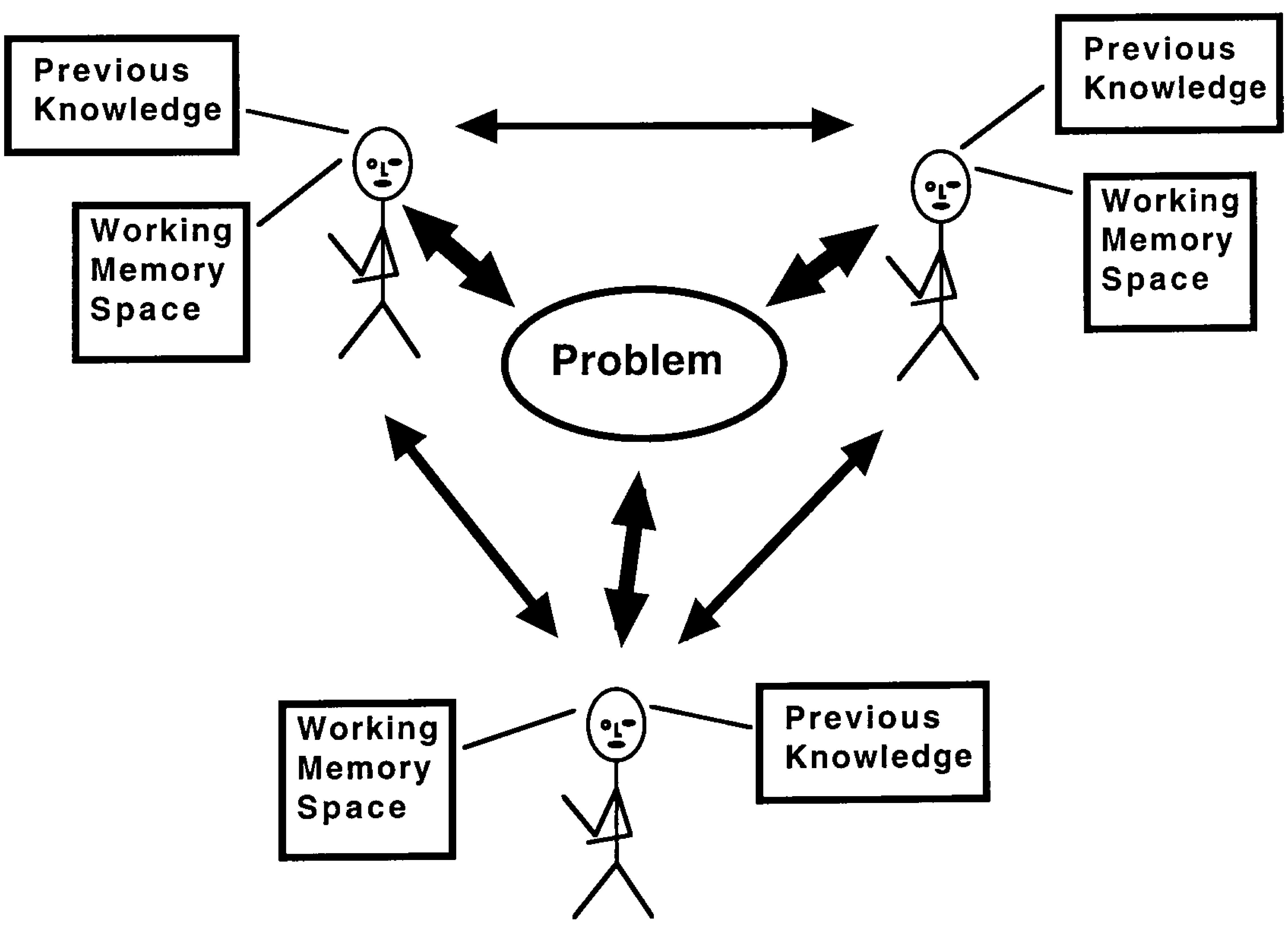


Figure 4.2 Problem Solving by Group

It is important to set the numbers of each group for effective discussion. If the group has just two members, a student could feel embarrassed with an uncooperative partner. In contrast, if the size of the group is too big, some pupils might not participate at all. According to the results of Heller and Hollabaugh's study (1992), they found that groups of two did not have the "critical mass" of conceptual and procedural knowledge for the successful problem solving in physics. In groups of four, one student was invariably left out of the problem-solving process. They finally concluded that the reasonable and optimal group size for prompting pupils' interactions is three members. This project adopted their suggestion and pupils were mostly placed in groups of three.

The problem solving exercises were called "UNITS", this being a neutral word that would not cause pupils to have unnecessary concerns. When used with pupils, this word was used and it was stressed to them that there was no assessment, the units were unconnected with examination marks and that answers obtained were not neatly "right" or "wrong". It was hoped that this would encourage genuinely open discussion which would provide useful insights into problem-solving.

The presentation of the problems was critical. The aim was, by the use of careful design and layout, to minimise difficulties solely due to poor presentation. Brevity was a feature and careful structuring of questions was employed and diagrams and tables were used wherever appropriate. Great care was taken to use language that was appropriate to pupils aged 14-17 in terms of the chemical ideas being used and in terms of normal English language which was likely to pose few problems to such pupils.

Because of the need to use the units with pupils at the right stage of their course (so that the unit theme fitted in with topics being studied), formal pre-testing of the units was not easy. As an alternative, units written early were pre-tested with one small group of pupils to check on style, presentation, language and difficulty level. Subsequent units reflected the observations from this pre-test. However, all the units were tried out with a team of research students (with variable background in chemistry). This proved very useful in that ambiguities were detected and removed. However, this was not seen as a full pre-test. Nevertheless, pupils seemed to encounter few difficulties that were related to language and presentation.

For flexibility of use and to ensure the least confusion when pupils were solving the problems, each unit was laid out in the same way: the title, the use of boxes and shading to guide the instructions of task on one side of A4 paper. In addition, space was specifically set aside to encourage pupils to write notes or calculations during problem solving. This was mentioned several times on the working paper and answer sheet to encourage pupils to talk and write in a group. Each unit had a separate "Answer sheet" which was completed by each group, sharing their answers and their working.

There was also an evaluation sheet, called an "Endpiece" which each pupil had to complete individually. In addition, a set of "Teacher's Guides" was devised and the original purpose was these would serve as guidance for teachers. However, the real experiment was administered by the researcher and the "Teacher's Guide" finally was not provided to teachers but was still used by the researcher. When pupils were engaged in doing problem solving, tape recording was conducted in some groups that began from the second data collection stage.

4.2 A Typical Unit

Here, one unit (unit 8 Moving Gases) is presented to illustrate the units' format. It has to be noted that pupils had no previous knowledge of the idea of diffusion in any quantitative sense and certainly know nothing of Graham's Law of Diffusion on which the problem was based. The unit is shown in full overleaf.

8

Moving Gases

Your Name: ....

Have you ever smelled the perfume from someone immediately after they entered the room ? This is because the particles of perfume are travelling through the air and have reached your nose. All gases travel but they do not all travel at the same speed. It has been found that different gases travel different distances in the same time.

The following data were collected from an experiment. The distances travelled by various gases in a set amount of time through a horizontal glass tube were observed. This was done at room temperature and the same pressure for all the gases.

Gas	Distance (cm)
SO_2	50
CH_4	100
HCl	66
SO_3	44
NH_3	94

You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Working as a group,

H	=	1
C	=	12
N	=	14
O	=	16
S	=	32
Cl	=	35.5

(1) Look at the results as a group and see if you can spot any pattern in these results ?

(2) How would you test to see if your pattern is correct ?

At this point, check with your teacher

(3) Predict how far you would expect chlorine gas (Cl_2) to travel under the same conditions. Show how you obtained your result.

Use this space for any notes, calculations, working etc

4.3 The Eighteen Units

A brief description of each of the eighteen units is given below. The units are given in full with teacher's guides in Appendix A.

Unit 1: Argon and Electric Welding (Type 6)

The idea for the development of this unit came from a study by Toby (1997). A newspaper report, which mentioned a tragic industrial accident when electrical-welding was taking place, is the starting point. The pupils are then asked to spot the chemical errors from a detective's statement and look for a reasonable explanation for the accident.

Unit 2: Which is the Best Fuel (Type 3)

Pupils are given some information about three fuels: coal, oil ($C_{11}H_{24}$) and gas (CH_4). The problem given to pupils is to find out which fuel will release most energy. They are given 1 Kg of each. They are taken through four steps to reach the answer.

The first part is to write the complete combustion equation of each fuel. The second part is to calculate the formula masses of each fuel. Told to assume that the energy released is related to the number of molecules formed, the pupils have to work out which fuel would give the most energy. Finally, they also have to judge whether this assumption is fair.

Unit 3: The Chewing Gum Problem (Type 4)

Does gum-chewing really help to fight tooth decay? The unit provides the basic ingredients of chewing gum for pupils but not enough information to reach an answer. Therefore, they have to search and make a list of useful information that they would need to know to solve the problem.

Unit 4: Fluoride Improves Tooth Decay? (Type 6)

The idea for the development of this unit was adapted from a study by Toby (1997). A statement about the influence of fluoride on tooth decay is quoted from a magazine. The pupils' task is to find out as many errors as possible in the statement.

Unit 5: The Glowing Splint Problem (Type 6)

The unit provides several results of experiments, which have shown that a glowing splint could be re-kindled by pure oxygen but not by NO2 or air. On the other hand, in another experiment, copper (II) nitrate breaks up when heated and the products consisted of a mixture of NO2 and O2 (in the ratio of 4:1, the proportion of oxygen being similar to that in air). This mixture re-kindles a glowing splint. Pupils have to try to explain the unexpected result.

Unit 6: Heat Packs for Mountaineers (Type 4)

The heat pack produces its heat by means of a chemical reaction. The ingredients of a heat pack (fine iron powder, fine carbon powder, salt and moist cellulose) is given to pupils. The instruction for using the heat packs is also provided along with a picture. Pupils are asked to work out how the heat pack works and where the energy comes from. They also have to suggest other metals that might substitute for iron in the packs.

Unit 7: Iron: How can we Obtain it? (Type 2)

The unit is related to iron, which is produced from iron ore in the blast furnace. The names and formula for three ores of iron are given. Pupils are also provided with a series of chemical equations for the process of producing iron from the iron ores. The main task is pupils have to select and rearrange the reasonable equations.

Unit 8: Moving Gases (Type 6)

The idea for the development of this unit came from a study by Kogut (1996). Pupils are introduced to the idea of gases moving (diffusion). Experimental data about five gases and the distance travelled are given in a table. By looking at the table, pupils are asked to spot any pattern in these results and test whether their pattern is correct or not. In addition, they also have to make prediction about the distance a sixth gas would travel under the same experimental conditions.

Unit 9: The Formula for Ozone (Type 4)

Pupils know the formula of oxygen. They have learned of ozone but do not know its formula. From a series of balanced equation, pupils are asked to try to establish a rule relating gas volumes to balanced equations. Afterwards, an equation for the break up of ozone to form oxygen is given. Pupils have to use the rule to work out the likely formula for ozone.

Unit 10: The Phosphorus Problems (Type 6)

To obtain pure phosphorus from rock phosphate is the main task. Pupils are given tabulated information about the various products from the industrial process: melting points, boiling points, reaction with water, reaction with air, and density. Although the problem seems simple using an understanding of methods of separation, it turns out to be more difficult if pure phosphorus is to be obtained safely.

Unit 11: The Leaking Pipe (Type 6)

The idea for the development of this unit came from a study by Toby (1997). A statement about an explosion resulting from a leaking underground pipeline is quoted from a local newspaper. The report said the pipeline carried liquefied propane gas, often called LP gas; natural gas liquids turn to gas when they come in contact with air. Pupils are asked to criticise the statement and re-write it in such a way that they explain why the explosion occurred.

Unit 12: Salt, Salts, and pH (Type 5)

The unit provides data about various salts and the pH of their solution in water. Pupils are asked to find patterns in the data, relating the salts and their pH. An example is given as a hint to help pupils drawing conclusion. At this stage, pupils have not met the ideas of salt hydrolysis.

Unit 13: *Solubility* *(Type 6)*

This unit provides solubility of a large number of compounds in a table. This is specified by reference to the cations (such as Na^+, K^+, Mg^{2+}, Pb^{2+}) and the anions (like OH^- , F^- , CO_3^{2-} etc.) are shown in the table. A definition of solubility is also provided. The pupils' first task is to draw out the patterns of solubility from the given table. Then pupils are asked to predict the result when mixing two solutions together, and predict the approximate solubility for two strontium compounds by interpreting trends in the data.

Unit 14: *The Swimming Pool Problem* *(Type 4)*

When people go swimming, some experience sore eyes. A story about swimming pool problem is described first. In the first question, pupils have to discuss what are the desirable properties for swimming pool. Then an equation showing the reaction of chlorine with water is provided and pupils are asked to list the ions formed. In the third part, a graph of pH and % of chlorine present as HOCl, and substances contain the N-Cl bond that are causing the eye soreness are given. Pupils have to use the given information to judge the best pH value of water for the swimming pool.

Unit 15: *Trees and Cars* *(Type 4)*

The idea for the development of this unit came from a study by Toby (1997). The unit is concerned with ways of reducing carbon dioxide emissions. Pupils have to make a rough calculation to check the quoted statement about how many trees would be needed to assimilate carbon dioxide emitted from a car in one year.

Unit 16: *Bonding* *(Type 6)*

The unit provides information about various types of chemical bonds (covalent, polar covalent, ionic, metallic) including patterns in melting points, boiling points, electrical conductivity, and solubility in water. Pupils are then given an imaginary budget £100 and asked to spend the money by selecting experiments (each of which is costed) which might help them to decide the type of bonding present in $AlCl_3$. They have to decide which tests will give most information in that they do not have enough money to pay for all the tests.

Unit 17: Chemicals from Salt (Type 6)

Sodium chloride produces sodium hydroxide, chlorine and hydrogen by electrolysis. During the electrolysis process, the products must not be allowed to mix. There are three types of electrolysis cells which are used in industry and the main features of the three cells are shown in a table. Firstly, pupils have to work out why the cell products are not allowed to mix during the process. Then pupils are asked to make decision about which process they would choose if they build a new factory, giving reasons for their choice.

Unit 18: Rates of Reaction (Type 5)

What kind of factors would influence the rate of chemical reaction? The unit looks at the reaction of zinc with dilute hydrochloride acid. The reaction time and the volume of hydrogen from four experiments are also given in a table. Pupils are asked to plot graphs according to these four results, and, after completing the graphs, they have to work out the factors that influence the speed of the reaction. At this stage, they have no prior knowledge of the factors.

Chapter Five

The Experimental Study

5.1 Aims and Experimental Structure

It can be argued that one outcome of education is to develop problem solving skills. Indeed, it has already been noted that this outcome receives a high profile in Scottish education although the conception of the skill may be inadequate. In recent years, research has provided evidence that success in problem solving is influenced by many factors. These factors, involve thinking (cognitive variables), emotional or motivational, and behavioural components are explored, based on various theories.

In Piagetian theory, the importance of the developmental stage of a student in problem solving and learning is highlighted. As Andre (1986) pointed out, the Piaget developed an approach to problem solving that focuses on mental logic. However, Ausubel (1978) has argued that the relevant prior conceptual knowledge is as important in solving problems as the developmental stage reached. Nevertheless, Ausubel did not examine the relationship between students' conceptual knowledge and problem solving strategies. To treat the relationship more explicitly, the Information Processing Model, which has been described previously (p17-18), has provided useful insights. The model emphasises cognitive variables such as working memory space, field dependency/ field independency, divergency/ convergency, and long-term memory that influence problem solving.

Many studies suggested that problem solving is a very complicated process, involving more than one cognitive variable as well as affective ones (Tsaparlis and Angelopoulos, 2000). In addition, Fisher (1995) has also stated that there are three sets of interacting factors involved in problem solving:

(1) Attitude: it includes interest, motivation and confidence.

(2) Cognitive ability: it includes knowledge, memory and metacognition.

(3) Experience: it includes familiarity with content, context and strategies.

By reviewing these large number of factors, it is difficult to explore all the factors in one project. Therefore, it is important to select a limited range of factors as this project's main concerns. Although some factors such as Working Memory Space, Field Dependency/ Field Independency, and Divergency/ Convergency are likely to be very influential in problem solving, they were, in this project, minimised in significance as much as possible by way of group work.

When pupils work together in groups, they have access to the working memory spaces of all the groups members. In addition, if writing and drawing are encouraged, there is even less likelihood of the working memory space being overloaded. Similarly, the influence of Field Dependency/ Field Independency and Divergency/ Convergency on problem solving also could be reduced by means of group work in that, within a group, it is likely that the group members will vary in these personal characteristics.

In this way, the project seeks to focus on the role of long term memory in problem solving. It is hoped to gained insights into the way concepts are stored and are linked to each other in assisting pupils in successful problem solving.

5.1.1 The Aims of the Study

The overall aim was to attempt to gain insights into the ways pupils solve open-ended chemistry problems. The focus is on the way the operation of long-term memory is a factor in determining success at such problems. This involves much more than the recall of information. The aim was to explore how concepts and linkages between concepts might influence success in solving such problems. It was also important to look for any other factors relating to long-term memory.

5.1.2 The Experimental Structure

The experimental structure depended on the development and use of a set of problems that were specifically designed to fit the chemistry syllabus but which also were of an open-ended nature. By allowing groups of pupils to attempt these problems, the aim was to observe the interactions between pupils and seek to deduce what factors were important in determining success or failure.

The experimental structure is presented in Figure 5.1. The eighteen problems were designed and pre-tested with one small group of pupils and trialled with six fellow students to check for any major ambiguities of language and structure. After modifying the eighteen problems, the first data collection proceeded with S3 and S4 pupils. In the light of observation and analysis of data, minor adjustments were made to some of the units and the evaluation sheet (named Endpiece) was slightly revised. Tape recordings were employed at the second and the third data collection stages. Again, minor adjustments were made as before after the second data collection stage. The third data collection stage was following until February 2000. The whole process is summarised in Figure 5.1.

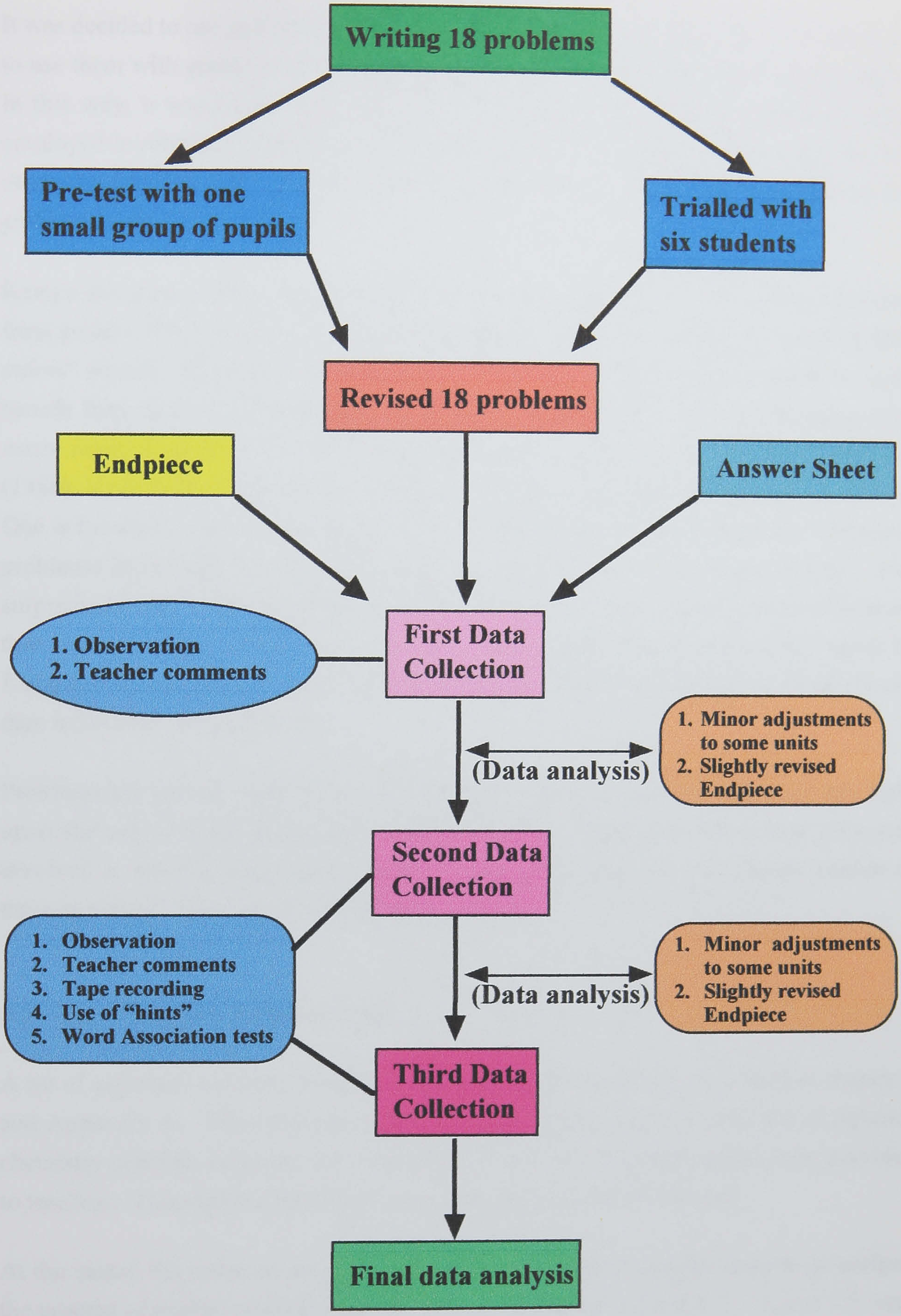


Figure 5.1 The Experimental Structure

5.2 Group Work in Problem Solving

It was decided to use problems that were too difficult for an individual pupil to solve and to use them with groups of three in order to explore the interactions between the pupils. In this way, it was hoped to be able to gain insights into the mental processes being employed in relation to concepts held in the long-term memories of the pupils. Several other studies have looked at the value of group work in the context of learning and problem solving.

Kempa and Ayob (1991, 1995) conducted two investigations that focused on learning from group work in science. They suggested that a significant amount of " learning from others" occurs. They also noted that even seemingly "inactive" group members could benefit from their involvement in group learning experiences. There do not seem to be many research studies that focus on problem solving in groups. In Garret's review (1986), he described two studies that refer to group versus individual problem solving. One is the study from Grant (1978) where she analysed the responses to two biological problems from high school pupils working either alone or in groups of four. Not surprisingly, she found that those working in groups solved problems more effectively than those working on their own. Another is the study from Foster (1981) where he found that small cooperative groups did significantly better on creating electrical circuits than individuals working alone.

Problems are solved better in groups. However, these studies do not throw any light upon the use of small groups as a method to gain insights into the mental processes involved in solving open-ended problems. In this project, most of groups consist of three members. The groups were formed randomly.

5.3 The Chemistry Problem Units

A set of eighteen chemistry problem units were devised and fully described in chapter 4 and Appendix A. When the researcher contacted with schools, a brief list of eighteen chemistry problem units and a few exemplary units with teacher's guide were provided to teachers. This enabled teachers to see where the units might fit best.

At the outset, the intention was to employ all the eighteen chemistry units to investigate the process of pupils' problem solving. However, four units (unit 3, 7, 11, and 17) were not used that because access to schools was not possible at times when such units would have been appropriate. The units used were selected after consultation with the teachers. Frequently, a unit was chosen simply because it fitted to the syllabus appropriately. Eventually, fourteen chemistry problem units were used in this project. They are listed as follows:

Unit 1	*Argon and Electric Welding*
Unit 2	*Which is the Best Fuel?*
Unit 4	*Fluoride Improves Tooth Decay*
Unit 5	*The Glowing Splint Problem*
Unit 6	*Heat Packs for Mountaineers*
Unit 8	*Moving Gases*
Unit 9	*The Formula for Ozone*
Unit 10	*The Phosphorus Problem*
Unit 12	*Salt, Salts, and pH*
Unit 13	*Solubility*
Unit 14	*Swimming Pool Problem*
Unit 15	*Trees and Cars*
Unit 16	*Bonding*
Unit 18	*Rates of Reaction*

5.4 Teacher's Guide

The teacher's guide was developed for each chemistry unit. They contained four sections: *introduction, learning outcomes, guidelines, and possible conclusions and answers*. The introduction includes *curriculum links* and *prior knowledge*, which provides guidance for the teacher in integrating the unit into the curriculum. The learning outcomes lists the most important objectives for solving the problem. The guidelines led the teacher to conduct and manage the experiment in class. The possible conclusions and answers provides a series of answers to help teachers when they use the unit in their class.

In reality, the teacher's guides were not used by teachers when the project proceeded in school. At the outset, it was hoped that school teachers would be willing to conduct the experiments in their class and the researcher did not need to be present on every classroom in order to gather large data. In this situation, the teacher's guide has to be provided to teachers. Unfortunately, this was not achieved because the school teachers preferred that the researcher administered the experiment in person after consultation with them. However, the teacher's guides were still helpful for the researcher to check out pupils' answers and for the school teachers if they decide to use it in the future.

5.5 Sources of Experimental Data

5.5.1 Answer Sheet

Before pupils began to solve problems, they were asked first to write their names on the answer sheet. This was for identification pupils only as the various pieces of paper and tape recordings were matched to each other. No pupil was identified for any other purpose.

The following instruction was presented on the sheet to guide the group to write their answer: "*After discussing with your group, write down the conclusions you think that you can make*". In addition, considering pupils might need more space to write their answers, a reminder "*If you need more space, use the other side*" was placed at the bottom of the answer sheet. Each group only need to fill in a piece of answer sheet. If the unit has different parts of questions, the numbers are printed on the sheet. Some exemplary Answer sheets see Appendix C.

5.5.2 Evaluation Sheet

The evaluation sheet was entitled "Endpiece" and was designed to be an integral part of the problem solving session. It provided an opportunity for pupils to reflect on the process of problem solving and to reveal how they had approached the problem and what were the features that were critical in terms of success. It consists of two kinds of questions: closed questions and open questions. The first section included thirteen closed questions:

The problem was enjoyable
The problem was difficult
I found that solving this problem was satisfying
The problem was completely new to me
I learned nothing from the problem
I had enough previous knowledge to solve the problem
I prefer solving problems on my own
We worked well together as a group
We did not share the work out evenly in our group
I found the group discussion helpful
At the end, we were not sure we had the correct answer
I could not have solved the problem by myself
I needed the other group members to help me remember background information

Responses were offered on a five-point scales, ranging from *strongly agree*, *agree*, *neither agree nor disagree*, *disagree*, to *strongly disagree*. Pupils indicated in this way their evaluation of each statement. These thirteen questions seemed to allow the pupils to reflect their feelings and experiences clearly and definitely, and as a result, these questions were not revised and were used throughout the experiment.

The second session contained eight open questions which tried to explore the underlying processes and the difficulties when pupils were engaged in solving problems. Pupils were given a small space to respond, enough for about a sentence. The set of open questions are:

(1) *What did you do first to solve the problem?*
(2) *What was the second step?*
(3) *What did you need to know before you began?*
(4) *What was the easiest part in the problem?*
(5) *What was a hindrance in preventing you from reaching a solution?*
(6) *How did you overcome obstacles in the problem?*
(7) *In what ways did working in a group help to solve the problem?*
(8) *What have you learned from the problem?*

After analysis of the data from the first data collection exercise, it was found that many pupils were not answering these open questions in a way that led to meaningful conclusions. This could have been due to not having sufficient time to reflect their opinion, or because the language used was difficult and ambiguous for them to understand. For example, in question 5 the term "*hindrance*" seemed a problem to many pupils. To answer question 1, many pupils wrote their answer as *"read the problems first*". Therefore, these eight questions were revised and made more precise. The English language of questions 1, 2, 5, and 8 were changed while questions 4 and 7 were deleted. The second version of the evaluation sheet contained six open questions which are listed below:

(1) *After reading the problem, what did your group discuss first?*
(2) *What was the second step your group took to solve the problem?*
(3) *What did you need to know before you began?*
(4) *What made it difficult for you to solve the problem?*
(5) *How did you overcome obstacles in the problem?*
(6) *The problem was quite difficult. What do you think you learned from trying to solve it?*

When the revised evaluation sheet was used at the second data collection stage, this time pupils coped better but there still a few groups which did not finish in a reasonable time and the opinions they reflected on these questions were also not very clear. For example, if the unit has two or more parts, some of their answers to question 1 were "*discuss part 1*". Answering question 5 (*how did you overcome obstacles in the problem ?*), most answers were "*by discussing with other members*". They seem to be unable to response to these questions meaningfully. Therefore, it was decided to revise these six questions again in order to collect the information more effectively. At the third data collection stage, there were two questions remaining in this section, these two questions are listed:

(1) *What did you need to know before you began?*

(2) *What made it difficult for you to solve the problem?*

The overall completed three versions of evaluation sheet are given in Appendix D.

5.5.3 Others: Hints, Word Association Tests, and Tape Transcripts

In the first stage of the experiment, an enormous amount of data was gathered from the Endpieces (pupil's self reflection on the process), the Answer Sheets (each group indicated the answers to the main steps of the problems), and the Problem Working Sheet (where there were spaces for working, doodling, playing with ideas). Despite the vast amount of information, it was felt that the insights gained on the mental processes of problem solving were limited. Several other strategies were developed to generate data that might be more focussed. Each of these strategies (Hints, Word Association Tests, and Tape Transcripts) is now described.

5.5.3.1 Hints

In two units, a set of written hints was provided. If in difficulty, groups were invited to ask for a hint. It was stressed to them that this was not any indication of failure on their part. It was hoped that, by examining which hints were sought most frequently, insights into the areas of difficulty would be observed.

In unit 8 " Moving Gases", a tabulated information was given which includes five gas formulas and their distances travelled under the same experimental conditions. Pupils were asked to spot any pattern in these results. Undoubtedly, many pupils were able to point out a common pattern: *the heavier the molecule is, the less distance it travels*. But it seems to be just a superficial answer. Can they draw a more exact pattern? Primarily it is expected that they can make a clearer connection between the distance travelled with the formula mass. However, no group could make this connection definitely at the first data collection stage. Hence, it was decided to develop an extra hint to help pupils achieve the objective. The hint is "*You will have noticed that the heavier the molecule, the slower it moves. Can you find a more exact relationship between the mass of the* *molecule and the distance moved?*". At the second data collection stage, pupils were given the hint after they wrote the common pattern.

In unit 15 "Trees and Cars", a quotation stated that one tree can use up the carbon dioxide which produced by one car. Pupils were asked to confirm if the quotation is correct. To solve this problem, pupils had to combine the combustion equations with chemical arithmetic. It was very difficult for them to handle these combined processes, most pupils encountered obstacles during solving this problem. Therefore, it was decided to develop some hints to help pupils to overcome the obstacles they have met. However, these hints could also provide valuable information about how the pupils managed the combination. The hints were given to pupils based on their enquiry. There are seven hints described as follows:

Hint 1 *A possible way to tackle the problem is to:*
- *(a) Calculate the mass of carbon dioxide formed by using a mole of octane.*
- *(b) Calculate the mass of octane used by an average small car in one year.*
- *(c) Calculate the mass of carbon dioxide produced by an average small car in a year.*

Hint 2 *Write a balanced equation for the combustion of octane. How many moles of carbon dioxide are formed by burning one mole of octane?*

Hint 3 *One mole (114 g) of octane gives 8 moles (352 g) of carbon dioxide.*

Hint 4 *What volume of petrol will the car use in one year?*

Hint 5 *If the car uses 4200 litres of petrol in one year and each litre has a mass of 700 g, what mass of petrol will be used by the car in one year?*

Hint 6 *352 g of carbon dioxide is produced by using 114 g of octane in the car engine. This means that, approximately:*
3 g of carbon dioxide is formed from 1 g of octane.

Hint 7 *You know that 2 940 000 g of octane is used by the car in one year. What mass (in grams) carbon dioxide will this produce? Now convert this into kilograms.*

5.5.3.2 Word Association Tests (WAT)

In science education, although problem-solving tests have been widely used to investigate the acquisition of concepts, they still have some limitations (Deese (1965) and Johnson (1969)). By contrast, the word association test (WAT) is a method which appears to put few constraints upon a pupil's responses and was often supported by many researchers. Deese (1965) claimed that the WAT is "perhaps as close to a context-free testing situation as can be devised". In work with university science students, comparing three method of mapping cognitive structure, Preece (1976) also gave a supportive suggestion that the word association test was a particularly valuable method for examining semantic relationships and cognitive structure in the context of science education. Furthermore, Shavelson (1972) proposed a clear illustration which focussed on the importance of the order of the response: "the underlying assumption in a word association test is that the order of the response retrieval from long term memory reflects at least a significant part of the structure within and between concepts".

Subsequently, several studies have used word association tests to explore the students' performance and problem solving abilities in chemistry (e.g. Kempa and Nicholls, 1983; Johnstone and Moynihan, 1985; Caphapuz and Maskill, 1987)

Kempa and Nicholls (1983) used word association test to explore the relationship between students' cognitive structure and their problem-solving abilities using algorithmic type problems in the context of chemistry. It was found that the cognitive structures of 'good' problem solvers are more complex and contain more associations than those of 'poor' problem solvers. Although they found out the links between different concepts observed for good and poor problem solvers do not appear very different, it still can be seen that where concepts are only weakly linked, access to one concept via another is not readily achieved, and then problem solving in which the link is essential does not occur.

In another study by Johnstone and Moynihan (1985), a word association test was used to map cognitive structure of areas of the Scottish Chemistry Syllabus for secondary schools. Based on the previous class tests in chemistry, pupils were divided into 'good' and 'poor' groups. Following the word association tests, a short multiple-choice achievement test (it consisted of twenty questions which mostly were based on the Scottish Certificate of Education O grade chemistry exam paper) was applied to the pupils. The results showed that there were significant differences between the emerging cognitive structure of 'good' and 'poor' pupils. In addition, it was also found that there was a statistically significant positive correlation between the students' performance in the word association tests and in the achievement tests. Only a few of 'poor' pupils were able to get the correct answer in chemistry tests. It provided further evidence that if a pupil possesses an unstable cognitive structure in a particular subject area then algorithmic problem solving may be inhibited in that area. In Cachapuz and Maskill's (1987) study, they had a similar findings as those which existed in Johnstone and Moynihan's study.

In this project, it was not thought helpful to employ the word association test to all problem units. Some units, such as unit 8 *(Moving Gases)* and unit 12 *(Salt, Salts, and pH)*, do not need many concepts to reach the solution. On the contrary, the more important factor to reach the solution of these units is reasoning ability and ability to deduce (the ability to make a rule or inference from a series of given data). After analysing the units' contents, it was therefore decided that two units (unit 2 and unit 6) would be appropriate to use the word association test to measure pupils' understanding of concepts.

A word association test was constructed in the following way. For the key concept, the related key words were suggested by "experts" who were familiar with both the chemistry and the school syllabus. These words were used as stimuli in the word association test. In unit 2 *(Which is the Best Fuel ?)*, eight stimulus words were provided. They are: *combustion, oxides, fuel, oxygen, energy, burning, heat, and carbon dioxide*. In unit 6 *(Heat packs for Mountaineers)*, nine stimulus words have been used. They are: *oxidation, metal, oxidation, energy, reduction, electron, oxides, redox reaction, burning.*

A booklet for each word association test was produced in which a page of instructions and two completed examples were followed by other pages, each headed by a different stimulus word. In the first page of the booklet, pupils were given the instruction as follows:

> *When you hear or see a word, it often makes you think of other words. In this study we would like to find out what other words are brought to your mind by some words used in Chemistry.*
>
> *On each page you will find a key word written many times. Say the word to yourself, and then as quickly as possible write the first word to come to mind in space Number 1. And then continue to write in the other spaces other associated words which come to mind.*
>
> *Continue in this way until you are told to turn the next page. There are no right answers. Write as quickly as possible since you are allowed only 30 sec. for each page.*

The second page of the booklet contains an example of responses to the general stimulus word "*Eagle*" and the third pages contains an examples of responses to the chemical stimulus words "*Acid*". The detail of these two word association tests are given in Appendix E.

For each stimulus word, pupils were required to list up to ten words which they thought to be closely associated with the stimulus word. In the studies by Kempa and Nicholls (1983), Cachapuz and Maskill (1987) and Bahar (1999), all of them gave thirty seconds for each stimulus word. In this project pupils were also given thirty seconds to response for each stimulus. Pupils did the word association test before they tackled these two units and the total test time (5 minutes) was controlled by the researcher.

5.5.3.3 Tape Recording and Tape Transcripts

Tape recording as a method to collect data has been in use widely for a long time, especially in the field of "*think aloud*" experimental studies. In this kind of study, when a student is asked to "*think aloud*" as he attempts to solve a problem, his verbalisations will be recorded for subsequent analysis. In a typical example conducted by Reif, Larkin and Brackett (1976), they found tape-recorded protocols useful for analysing the problem solving processes of college physics students prior to devising materials to teach problem solving skills.

In this project, pupils were asked to solve a problem by group discussions. It is considered that the group discussions might be helpful to provide some critical evidence, because every pupil has to share their thoughts during the process of problem solving. As regards the difficulty the pupils will be encountering and the way they overcome them, it is hoped that insights might be gained by analysing the tape transcripts. All tapes were listened to by the researcher but only some of them were transcribed in full, this being carried out when it appeared that some useful insight might be gained.

5.6 The Pupil Samples

Almost all Scottish Secondary schools are 6 year comprehensives (aged 12-18). In this project, the schools chosen were a cross-section of such schools. The pupils (n=668) who participated in this study were 14-17 years old, following Standard Grade or Higher Grade Chemistry in Scotland Secondary schools. They were drawn from eight secondary schools including city, urban areas and rural areas. Each school provided one or more whole classes for participation in this study from S3, S4, and S5 stages. The teachers tended to be enthusiastic over taking part in this study because they thought problem solving was important and there was a lack of suitable materials.

The first data collection began in May/ June 1999 and involved 343 mainly S3 pupils (aged 14). The second data collection followed in September / October 1999 and involved 216 (mainly S4 and a few S5) pupils. The third data collection was carried out from November 1999 to February 2000, 109 (S4 and S5) pupils participated the study.
In addition, there was an opportunity to have 63 Taiwanese pupils (aged 16) participating this project. They were enrolled in the department of chemical engineering in a municipal vocational high school. They have a strong chemistry knowledge

background such as general chemistry, organic chemistry and analytical chemistry. Under a very different learning environment and culture, did they solve problems differently from Scottish pupils? Considering the limited time the researcher stayed in Taiwan, it was decided to use one unit for Taiwanese pupils. Unit 2 was then selected and translated along with its answer sheet and evaluation sheet into the Chinese language and taken to Taiwan to test it.

5.7 The Methods of Data Collection

In order to gain as much a range of data as possible, the following methods were used in this project:

(1) Pen-and-paper work with group discussion sessions

Three kinds of papers were given to pupils in turn: the problem sheets which included spaces for notes and working, the answer sheets, and the questionnaires (the "Endpiece"). For distinguishing these three papers easily , they were printed in different colours. Pupils were asked to read the problem sheets first, and then group discussion was encouraged strongly. When they were engaging in solving the problem, one of the group members had to fill their agreed answers on the answer sheet. After pupils finished the task, the questionnaire sheet entitled " Endpiece" was given to each pupil to complete on an individual basis.

In the Answer sheet, the answers for the chemistry problem derived from each group discussion might be correct or incorrect. It became clear that it could provide some evidence about what prior knowledge and chemistry misconceptions the group might have. However, there is a weakness in that these correct or incorrect answers were not always sufficiently detailed to allow for a plausible interpretations about the way they solved the problem in groups. Bloom and Broder (1950) have argued the assumption that the mental processes of students can be inferred from their written answers papers. They claimed that this kind of research was "*inappropriate, superficial*". Moreover, Cowan (1977) also stressed the dangers of making inferences from written answers alone, even where students have been asked to show their "working". In the light of this, it was thought important to ask pupils to reflect their opinions and thoughts on the Endpiece sheet, because it could give the researcher useful insights into the pupils' approaches to solving problems.

(2) Classroom observations

The process of problem solving is complex and some behaviours might not be verbalised and noted on the various sheets.. By looking only at the problem sheet and answer sheet, it is not always sufficient to provide entirely clear and definite information. Therefore, the researcher observed and took notes to document actions that were performed but not verbalised by pupils when they were engaged in solving problem. The following list was used :

(a) *Did they discuss well?*
(b) *Did a leader appear?*
(c) *Were there by-standers?*
(d) *What were difficulties?*
(e) *What questions were asked of teacher?*
(f) *Was previous knowledge misleading or unhelpful?*
(g) *Any evidence relating to long term memory and working memory space?*

(3) Teacher comments

The fourteen chemistry problems were conducted in various schools. It is obvious that pupils' background knowledge and characteristics vary among these schools. According to Tingle and Good (1990), it has been found that successful problem solvers in chemistry demonstrate confidence and persistence in addition to strong background knowledge. Many studies have shown that problem solving would be influenced by the background knowledge that pupils already have as well as pupils' characteristics, hence it might be helpful if the teacher can provide these kind of information. When pupils finished the problem-solving task and left the classroom, the researcher then tried to talk to teachers to obtain some comments about their pupils .

(4) Tape recordings:

Although the above three methods could provide much useful information, it was thought that it might not be sufficient to lead the researcher to make clear conclusion for some units. Therefore, many group discussions were recorded in order to provide greater evidence and additional information. Pupils were informed that their discussion would be tape-recorded, and again, they were encouraged to talk while solving problems. Although there was some evidence that the presence of tape recorders made pupils a little nervous, in most cases it was clear that the groups ignored the recorders and carried on their conversations in an uninhibited way. The actual recording time varied from unit to unit but was often 30 minutes or more. Tapes were only transcribed when there was some evidence that potentially revealing insights might be gained.

5.8 The Experimental Procedure

The experiments were administered in eight schools from February 1999 to February

2000. At the beginning, with each class, in order to put the pupils at ease, they were told: *the experiment was not to be marked at all, that answers were analysed only by the researcher and would not be shown to your teacher.*

Many units took about 30-35 minutes including the Endpiece. Others were slightly shorter or slightly longer. Typically, a class undertook one unit. If the period length was long enough, two units were attempted, an 'easier' one followed by a 'harder' one.

There were three sequential data collection stages, the total number of schools, pupils and units used are shown in the Table 5.1. Choice of units to be used was largely determined by ther syllabus coverage in a particular school.

Table 5.1 The Sample Pupils and the Units

Data Collection	School	Pupil	Unit	Year	Tape Recording
First Data Collection	School A	226	4,5, 8,9,12,13	S3, S4	no
	School B	78	1,16	S3, S4	no
	School C	14	16	S3	no
	School D	25	18	S3	no
Second Data Collection	School E	66	2,6,8,9	S4, S5	yes
	School F	98	1,2,10,13	S3,S4,S5	yes
	School G	52	8,9	S4	yes
Third Data Collection	School H	39	5,15	S4, S5	yes
	School I	34	14,15	S4, S5	yes
	School F	36	13,15	S4, S5	yes
	*Taiwan	63	2	S5	no

* Taiwan: samples were from one of Taiwan's vocational secondary schools

5.8.1 The First Data Collection Stage

Four schools were involved at this stage. School A provided several classes which consisted of 226 pupils. Because the number of pupils was large and they were placed in two laboratories, it was difficult for the researcher to manage the experiment in two different rooms simultaneously. Therefore, an extra researcher was invited to help managing the experiment in this school. The experiment proceeded for a whole day. Six units were used: units 4, 5, 8, 9, 12, and 13. During the process of the experiment, some of the teachers stayed at the room to observe their pupils while others left the room and were not involved in the experiment. The second school provided two classes which consisted of 78 pupils. Two units were used which are unit 1 and 16. The other two schools only provided small number of pupils to participate the task, each school used one unit only. There was no tape recording at this stage.

5.8.2 The Second Data Collection Stage

After the first data collection, the researcher reviewed and analysed these data. It was found that the evidence from paper work, teacher comments, and observation seemed insufficient to draw any conclusions. Since the experiment was undertaken by at least four or five groups at the same class, it is difficult for the researcher to observe every group carefully at the same time and thus some useful information might be missed. Therefore, it was decided to use the tape recording at the second data collection session. In addition, some units and evaluation sheets also have been slightly revised to remove pupils' confusion and obstacles they encountered during the experiment.

There were three schools and 216 pupils including S3, S4 and S5 grade involved at this stage. The teachers and pupils were enthusiastic to undertake the experiment, one school even promised to participating in the third experimental stage.

5.8.3 The Third Data Collection Stage

Three schools in Scotland and one school in Taiwan were involved in this stage of the experiment. All the Scottish pupils were studying in S4 and S5 grade chemistry course. The total number of pupils was 172. Tape recordings and other method such as Hints and Word Association Tests were used in this session.

Chapter Six

The Type 4 Problem

According to Johnstone (1993), the type 4 problem is described as: data incomplete, method unfamiliar, and goal given. Pupils have to weigh up possible methods and select or acquire the data required in order to solve such problems successfully. The following units were classified as the type 4 problems:

Unit 3: *The chewing gum problem (not used in this project)*
Unit 6: *Heat packs for mountaineers*
Unit 9: *The formula for ozone*
Unit 14: *The swimming pool problem*
Unit 15: *Trees and cars*

6.1 *Unit 6*: Heat Packs for Mountaineers

The unit was used at the second data collection stage with 7 groups (21 S5 pupils) taking part in solving it. These pupils had been taught the concepts of oxidation and the reactivity of metals. A Word Association Test was conducted before they did the unit to test their understanding of the concept of oxidation. The unit was in two parts (the full unit is shown in Appendix A):

(1) *Work out how the heat packs works and explain where the heat energy comes from?*

(2) *Why is iron powder used as the main material for the heat packs? Suggest any other powdered metal that might be used, giving reasons for your choice.*

6.1.1 Word Association Test Results

The main concept in this unit is *Oxidation* and pupils only made strong connections with four stimulus words: *reduction, electron, redox and oxygen*. They did not link oxidation to *energy, metal, burning and oxides*. The lack of direct connections between oxidation and burning, and oxidation and energy is surprising. In fact, the heat packs releases heat energy that stemmed from the oxidation of iron. Despite this lack of direction connection, most pupils were able to reach answers.

The impression from the concept map is that pupils' understandings tend to be somewhat theoretical, with both redox and the electron being heavily linked. The full concept map is presented in Figure 6.1 (overleaf).

Unit 6 Heat Packs for Mountaineers

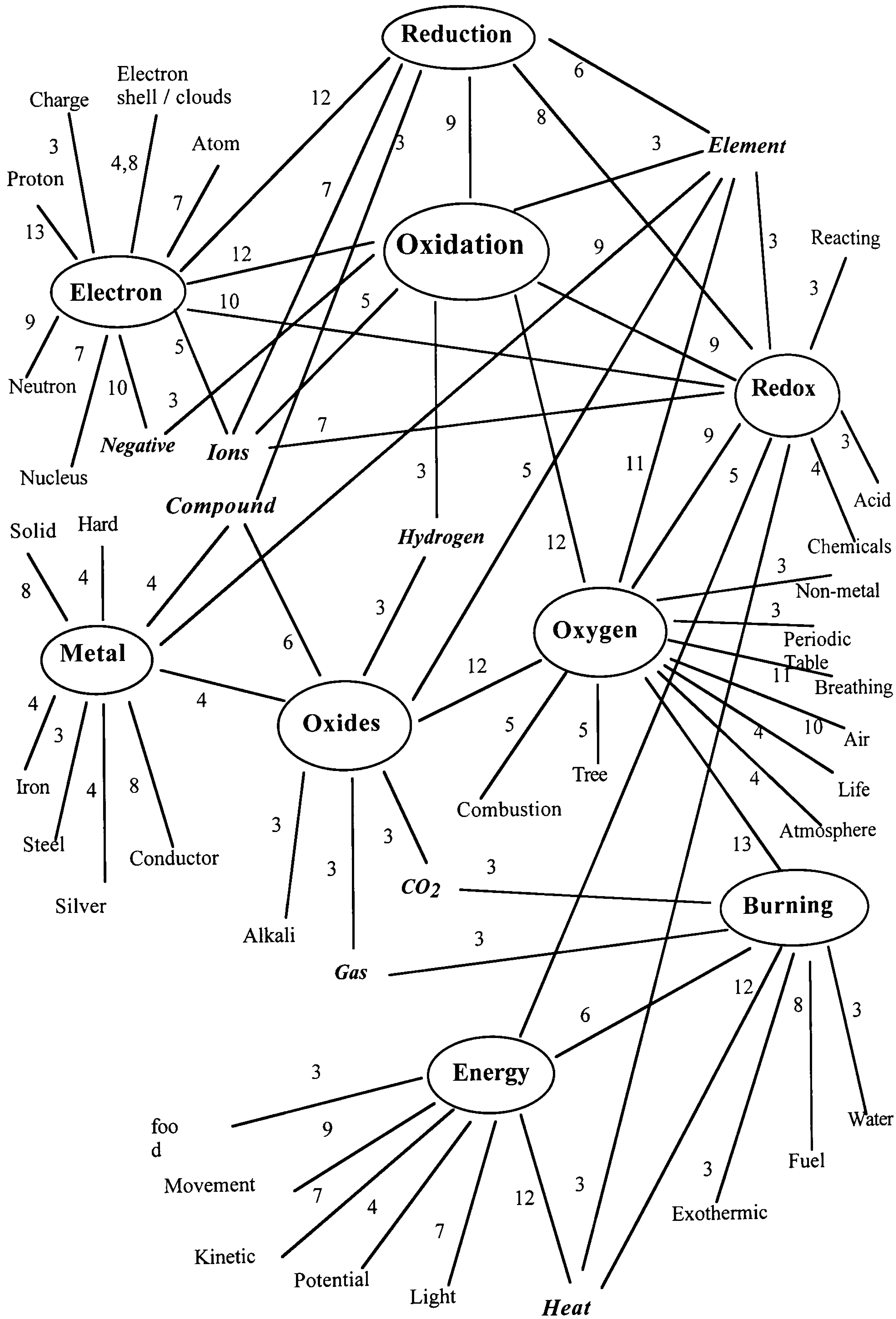


Figure 6.1 Concept Map I (Unit 6)

6.1.2 Pupils' Answers to The Unit

For part 1, although the key data of *"oxygen and air"* did not appear in the working sheet, most of the groups were able to spot this hidden information to reach a correct solution. They stated that the heat energy comes from the reaction of oxygen in the air with fine iron powder. One group even mentioned that the iron reacts with air producing Fe_2O_3 is an exothermic reaction and is self-sustaining. In addition, some groups considered the functions of the other constituents. For example, one group wrote "*the moist cellulose acts as a conductor to draw the heat away from the core*"; another group thought that "*the cellulose can moisten the salt and speed up the reaction allowing electron movement*". One group mentioned that the "*other three components (fine carbon powder, salt and moist cellulose) are catalysts*". Two groups said that the heat is travelling through the porous fabric onto the hand which then keeps the person warm. It seems to be clear that the S5 pupils have enough prior knowledge to solve the problem. In general, they did not mention the concept of *Oxidation* but their answers were usually correct.

Only one group produced an unclear answer. To quote from the answer sheet, they said "*when rub hands together, the particles collide with each other and move from positive ions to negative ions which produces the heat energy. The oxygen comes through the porous so when you rub your hands it produces fabrics heat energy which kick starts the reaction*". They seemed to think that the heat energy came from the collision of particles but they did not clearly refer to oxygen and iron.

For part 2 (*why is iron powder used as the main material*?), most pupils understood that iron is a cheap metal, a good reactant with oxygen, a heat conductor, not poisonous and not a finite resource. Only one group wrote a slightly misleading answer: *because iron rusts quickly and is speeded up by salt*. It is obvious that most of pupils possessed firm previous knowledge about iron.

However, when they were asked to "*suggest any other metal might be used in the heat packs*", most of groups could not provide a reasonable choice. Considering the reactivity of metals and their price, manganese is the best choice. Only one group chose manganese because it has similar chemical properties to iron. Four other groups chose zinc because it is cheap and reasonably reactive. Two groups did not make a reasonable choice. The group who thought iron rusts quickly and is speeded up by salt also failed in this part: they chose aluminium or lead because they "*corrode quickly*". In fact, the idea of "*iron rusts quickly*" and "*aluminium or lead corrode quickly*" are not necessarily totally wrong. They seemed unaware of the conditions that metals to corrode at the correct rate.

Another group chose three kinds of elements to substitute for iron which were:

(a) copper: because it is a "*radiator*" and cheap;
(b) aluminium: because it keeps everything warm and very light;
(c) carbon: because it stops buildings from corroding.

6.1.3 Responses from Endpiece

This unit used the second version of the Endpiece which included thirteen closed questions and six open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed response to closed questions is shown in Table 6.1.

Table 6.1 Summary of Fixed Response Questions in Endpiece (Unit 6)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	6	10	4	1	0
The problem was difficult.	3	10	5	3	0
I found that solving this problem was satisfying.	6	12	2	0	1
The problem was completely new to me.	6	12	2	0	0
I learned nothing from the problem.	0	0	6	12	2
I had enough previous knowledge to solve the problem.	2	10	5	1	3
I prefer solving problems on my own.	1	4	6	8	1
We worked well together as a group.	8	10	3	0	0
We did not share the work out evenly in our group.	1	0	7	6	6
I found the group discussion helpful.	6	11	3	1	0
At the end, we were not sure we had the correct answer.	2	6	5	7	1
I could not have solved the problem by myself.	5	3	9	4	0
I needed the other group members to help me remember background information	5	5	5	4	2

Although the samples were small, the evidence is clear that the problem was difficult, completely new but enjoyable to pupils. They also found that solving the problem was satisfying. They thought they had enough previous knowledge to solve the problem. This is consistent with the way they revealed appropriate answers to the problem.

As the responses to six open questions in the second version of the Endpiece, pupils expressed their opinions:

Question 1: *After reading the problem, what did your group discuss first?*

Typical responses were:

(a) whether the iron is a catalyst in the reaction;
(b) how the four ingredients reacted with other;
(c) why the fabric was porous;
(d) why the bag was suspended and rubbed;
(e) what a heat pack was and used for;
(f) how the pack worked and what the reactants were.

It is clear that different groups approached the procedure in very different ways.

Question 2: What was the second step your group took to solve the problem?

Typical responses were:

(a) *debated what the product of the reaction was;*
(b) *read through instructions or main point over and over again;*
(c) *figured out why the fabric was porous and why the other compounds were needed;*
(d) *worked out what each substance would do;*
(e) *discussed why iron was used as the main material;*
(f) *what the other components did;*
(g) *what are the conductors.*

This again illustrate the diversity of approaches used.

Question 3: What did you need to know before you began?

Typical responses were:

(a) *how iron reacts with air / oxygen;*
(b) *similar chemical properties;*
(c) *why the compounds were in the bag;*
(d) *if iron was a heat conductor;*
(e) *if iron reacts quickly when in connection with salt;*
(f) *general information on the elements;*
(g) *the properties of iron and how catalysts work in a chemical reaction;*
(h) *basic chemistry.*

They seemed to see that the properties of iron were important.

Question 4: What made it difficult for you to solve the problem?

Typical responses were:

(a) *disagreement and controversial issues in the group;*
(b) *finding out what is the other reactant with iron;*
(c) *we thought that it was near impossible with only one way to solve it;*
(d) *we had to find out what caused the reaction;*
(e) *we did not know why the compounds were there;*
(f) *we could not figure out how the heat would get out and be produced;*
(g) *we didn't know why carbon was used;*
(h) *to find another suitable element in place of iron;*
(i) *how to get the information;*
(j) *not being sure whether we were on the right tracks or completely of the issue.*

The diversity of answers seems to suggest that there was a wide range of approaches adopted.

Question 5: How did you overcome obstacles in the problem?

Typical responses were:

(a) *debated each of the possible answers/ opinions to see which was most likely;*
(b) *discussed different answers within the group;*
(c) *working together and remembered things from our previous knowledge;*
(d) *shared ideas and gave our opinions;*
(e) *reread through the passage and gave some suggestions;*
(f) *using other examples and seeing what the significance of the components were.*

Question 6: What do you think you learned from trying to solve it?

Typical responses were:

(a) *remembering previous chemistry is important for solving harder questions;*
(b) *we have to take into account other possibilities than the ones which are in front of us;*
(c) *we need to look at other aspects of information rather than information given;*
(d) *iron would react with oxygen and it could speed up by heat (or heat would be a catalyst);*
(e) *to think about different ways in which reactions could take place;*
(f) *how a heat pack really works;*
(g) *to know what types of problems may come up in the exam;*
(h) *I learned to work my mind more extensively rather than coming up with a simple idea;*
(i) *chemistry is around us all the time;*
(j) *it is helpful working in a group so that each of the members can help out.*

Although these comments reveal areas of chemistry which the pupils have learned, the more interesting comments [(b) and (c)] suggest that they have widened their ideas about approaches to problem solving.

6.1.4 Information from Tape Recordings

Although most groups were recorded, little of significance emerged from the recordings. Almost all could handle the problem without too much difficulty.

6.1.5 Analysis Summary

It appears that pupils had a fairly competent understanding of the concepts related to oxidation and reactivity of metals. From observation, they seemed to move quickly through an unsure phase in their discussion until they appreciated that the major constituent was iron and that, therefore, this component must the key one in the reaction. There was another move in their thinking when they appreciated that nothing else in the bag reacted easily with iron to produce and that it was oxygen from the air which was involved. Once these key pieces of information were understood (and this seemed to happen fairly quickly), by diverse routes they moved towards answers.

6.2 *Unit 9*: The Formula for Ozone

The unit was used twice. At the first data collection stage, 8 groups consisted of 24 (S4) pupils took part in solving it. The unit is in two parts. In part 1, a series of balanced equations were given and pupils were asked to establish a rule based on these equations. In part 2, they had to apply the rule to work out the likely formula for ozone. The equation given to pupils is shown :

Ozone (?)	$\longrightarrow$	Oxygen (O_2)
(20 ml)		(30 ml)

All groups were able to obtain the correct volumes of formaldehyde (CH_2O) and carbon dioxide (CO_2) in part 1. Nevertheless, most pupils could not establish a rule relating gas volumes to balanced equations. As a result, only two groups of pupils obtained the correct formula of ozone (O_3). It seemed likely there might be some specific barriers preventing the development of a rule and its application.

Looking again at this unit, it was found that those four given equations in part 1 were in the same style: every molecular formula was given and the volume of product was unknown. But in part 2, the equation in the problem was set in the reverse direction: the volume of product was given while the formula of ozone was unknown. It is important to explore whether this change in the direction of thinking resulted in pupils' failure to solve the problem. To test this, the unit was modified. In part 1, an question was replaced to give an example (as question 2) in the opposite direction:

At about 450 ° C, phosphorus gas breaks up according to the following equation:

P_4 (g)	$\longrightarrow$	?
(20 ml)		(40 ml)

What is the formula of phosphorus gas above 450 ° C ?

The old part 1 question 2 was replaced as question 1. After this minor modification the unit was used at the second data collection stage. 14 groups consisting of 37 pupils (S4) took part in this stage of test.

6.2.1 Pupils' Answers to The Unit

To work out the likely formula for ozone, pupils first have to establish a rule: *gas volumes are related to balanced equations*. By using the rule, they were likely to obtain the formula of ozone (O_3). At the first data collection stage, it has been noted that all groups obtained the correct volumes of formaldehyde (CH_2O) and carbon dioxide (CO_2) but rarely established the rule. Only two groups obtained the correct formula of ozone. At the second data collection stage, almost all pupils obtained the correct volume of carbon dioxide (except one group which did not seriously engage in solving the problem). Most groups were also able to reach the formula of phosphorus (P_2), only four groups failing in this part. For the formula of ozone, this time ten of the fourteen groups pupils reached the answer successfully. It seems that the introduction of the phosphorus equation (given volumes, unknown formula) has enabled many groups to develop and apply the rule. This suggests that knowing a process in one direction does not guarantee the successful application of the process in the reverse direction.

6.2.2 Responses from Endpiece

This unit used two versions of the Endpiece. The first version of the Endpiece which included thirteen closed questions and eight open questions. The second version of the Endpiece which retained the same thirteen closed questions but revised the eight open questions to six. The pupils' responses to the Endpiece are summarised below. Firstly, the summary of fixed response to closed questions is shown in Tables 6.2 and 6.3.

Table 6.2 Summary of Fixed Response Questions in Endpiece (Unit 9 First Data Collection)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	0	2	6	10	6
The problem was difficult.	13	6	2	3	0
I found that solving this problem was satisfying.	0	4	9	10	1
The problem was completely new to me.	10	9	3	2	0
I learned nothing from the problem.	1	1	5	16	1
I had enough previous knowledge to solve the problem.	0	4	2	14	4
I prefer solving problems on my own.	0	1	2	11	10
We worked well together as a group.	6	14	3	0	1
We did not share the work out evenly in our group.	3	3	4	9	5
I found the group discussion helpful.	5	15	1	1	1
At the end, we were not sure we had the correct answer.	9	9	1	4	1
I could not have solved the problem by myself.	11	6	3	3	1
I needed the other group members to help me remember background information	8	6	3	4	3

Table 6.3 Summary of Fixed Response Questions in Endpiece (Unit 9 Second Data Collection)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	5	14	10	5	3
The problem was difficult.	9	22	5	1	0
I found that solving this problem was satisfying.	3	13	13	7	1
The problem was completely new to me.	12	22	1	2	0
I learned nothing from the problem.	1	1	8	19	8
I had enough previous knowledge to solve the problem.	1	9	10	11	4
I prefer solving problems on my own.	1	4	6	16	9
We worked well together as a group.	9	20	4	1	2
We did not share the work out evenly in our group.	0	4	10	18	4
I found the group discussion helpful.	6	22	4	3	2
At the end, we were not sure we had the correct answer.	6	17	6	8	0
I could not have solved the problem by myself.	11	15	6	4	0
I needed the other group members to help me remember background information	1	22	7	6	1

As can be seen from these two tables, only 2 pupils (of 24) enjoyed doing the problem in its first version. They also found that solving this problem was not satisfying (20 of 24). On the contrary, almost half of pupils who attempted the second version felt the problem was enjoyable (19 of 37) and satisfying (16 of 37). Comparisons indicate that these patterns are significantly different ("Enjoyable": $\chi 2=15.4$, df2, sig. at 1%); "Satisfying": $\chi 2=5.9$, df2. sig. at 5%). In addition to referring to whether they have enough previous knowledge to solve the problem, the pupils in the second version (10 of 37) were a little more confident than the pupils in the first test (4 of 24). Indeed, it has emerged that both of them did not have quite enough previous knowledge about chemical formula and balanced equation. However, pupils found both versions were difficult and completely new.

As the responses to **eight open questions in the first version of the Endpiece**, pupils expressed their opinions which are listed as the following.

Question 1: What did you do first to solve the problem?

Most pupils wrote "*read the problems or sheet first*", only two pupils wrote meaningful opinions: "*look for the patterns in the equation*" and "*compare the equations*". Thus it was considered that the problem had to be revised in order to avoid unhelpful responses.

Question 2: What was the second step?

The opinions pupils wrote were "*discuss the problem or possible answers*" or "*try to work out the formula*". Obviously, it also has to be revised as well.

Question 3: What did you need to know before you began?

Typical responses were:

(a) *numbers of molecules in the formula;*
(b) *what the formula meant;*
(c) *what the letters in the equation stand for;*
(d) *knowledge of equations;*
(f) *amounts of molecules compared to volume;*
(g) *things about ozone.*

Clearly, they appreciated the importance of knowing about equations and molecules.

Question 4: What was the easiest part in the problem?

The unit has two parts and part 1 was obviously easier than part 2. Some pupils just directly spotted that "*part 1*" was the easier part. Others reflected that "*nothing in this problem was easy*". This question was deleted in the second version of Endpiece.

Question 5: What was a hindrance in preventing you from reaching a solution?

Typical responses were:

(a) *did not have enough knowledge;*
(b) *did not understand what to do;*
(c) *missed most of the lesson;*
(d) *other group members' interference;*
(e) *it was hard.*

From questions raised by several pupils, it was clear that the meaning of the word "*hindrance*" was unfamiliar to some. It was necessary to slightly adjust the question to be more clear and understandable for pupils.

Question 6: How did you overcome obstacles in the problem?

Most pupils wrote they overcame obstacles by "*discussed the problem*" or "*guessed*". They did not write a reasonable description.

Question 7: In what ways did working in a group help to solve the problem?

The general responses from pupils were "*had more ideas to solve the problem*" or " *we could discuss any possible answers*". A few pupils did not have answers to the question. Some pupils even replied that they did not solve the problem because none of them knew anything.

Question 8: What have you learned from the problem?

Some pupils expressed that they learned how to work out equations and knew the formula of ozone is O_3. There were still many pupils did not answer the question or felt they learned "*nothing*".

As the responses to **six open questions in the second version of the Endpiece**, pupils expressed their opinions which are listed as the following.

Question 1: *After reading the problem, what did your group discuss first?*

Typical responses were:

(a) *the breakdown of molecules and the balance of molecules;*
(b) *the volumes of molecules;*
(c) *if there was another element in ozone;*
(d) *the ratios of the formula;*
(e) *how to found out the pattern from the example equations.*
(f) *talked about the part 1 problem.*

These comments illustrate the way conversation focussed on the mechanics of molecular understandings - essential as a basis for solving this problem.

Question 2: What was the second step your group took to solve the problem?

Some pupils simply answered to "*work out part 2 of the problem*". Only a few of pupils were able to describe a meaningful approach:

(a) *looked at the number of moles in the compounds;*
(b) *looked at the volumes of ozone and oxygen;*
(c) *tried to relate the molecules to each other;*
(d) *comparing the volume in each molecule;*
(f) *used the example equations to work out whether number of molecules was involved.*

Parallel to their responses to question 1, these comments show how the pupils were moving from the molecular understandings to explore the concept of number as it applied in this problem.

Question 3: What did you need to know before you began?

It was often mentioned by pupils that they needed to know "*how to balance the equations*". Others, referred to "*the correspondence of volume to mole*", "*moles*', "*the symbols of elements or compounds*" and "*how to find number of molecules*".

Question 4: What made it difficult for you to solve the problem?

Many pupils stated that the difficulties they were meeting were "did not know how to solve part 2" or "did not know it was to do with *moles*". Amazingly, some pupils even thought because they did not know the formula of ozone also hindered them from reaching the solution.

Question 5: How did you overcome obstacles in the problem?

Not surprisingly, most pupils expressed a similar reply: *discussed the problem or work together.*

Question 6: What do you think you learned from trying to solve it?

The things they learned were "*more about ozone*", "*group work is better than working alone*" and "*how to work out volumes from balancing equations*".

6.2.3 Information from Tape Recordings

Although most groups were recorded, little of significance emerged from the recordings. Almost all could handle the problem without too much difficulty.

6.2.4 Analysis Summary

It is clear that most pupils can manage to handle formulae and equations although it is not so clear that they really understand what a formula in an equation can represent. This is a source of immense confusion in that such a formula can represent a single molecule and, in this particular problem, it was representing a very large number of molecules. At this stage, the concept of the mole would not be clearly established (indeed, can it ever be said that it is clearly established at school level ?) although some appreciated that the concept might be useful. The major observation to be made is that by learning a procedure on one direction is no guarantee that it can be applied in the opposite direction. This suggests that links in long term memory need to be made in both directions in order for the linkage to be soundly made.

6.3 *Unit 14*: The Swimming Pool Problem

The unit is in three parts. First, pupils were asked to list the desirable properties of water for a swimming pool. This was not the main task but was meant to encourage pupils to discuss in groups. In part 2, an equation showing the reaction of chlorine with water was given as below and pupils had to write down the ionisation equation for each acid, the latter acid being totally unfamiliar.

$$Cl_2(g) + H_2O(l) \longrightarrow HCl(aq) + HOCl(aq)$$

Finally, pupils had to use the given information and a graph to judge the best pH value of water for the swimming pool. 17 groups, consisting of 48 pupils, took part in solving this unit. During the process of problem solving, many pupils were confused about the term "*ionisation*" and asked for help.

6.3.1 Pupils' Answers to The Unit

For the desirable properties of water, all pupils obtained sensible ideas. The water has to be warm, clean, smells nice, colourless, no germs and a sufficient amount of chlorine. In part 2, at the outset many groups did not know how to write the ionisation equations. Because these groups were unable to proceed further, they were shown another example of writing an ionisation equation. With this help, they seemed confident to proceed and they managed to write reasonable equations as required.

To answer the question : *when the water in swimming pool is chlorinated, what will happen to the pH of the water*, most pupils understood that the pH of the water decreases and turns more acidic. However, three groups answered it incorrectly. One group wrote "*the pH will increase because chlorine is an alkali*"; another group wrote "*the pH would increase because of the positive hydrogen ions*"; the third group wrote " the pH drops because it is acidic and *goes towards O*".

6.3.2 Responses from Endpiece

This unit used the third version of the Endpiece which included thirteen closed questions and two open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed response to closed questions is shown in Table 6.4.

Table 6.4 Summary of Fixed Response Questions in Endpiece (Unit 14)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	3	11	20	7	7
The problem was difficult.	9	23	11	4	1
I found that solving this problem was satisfying.	7	11	18	8	4
The problem was completely new to me.	12	20	11	5	0
I learned nothing from the problem.	3	7	14	15	9
I had enough previous knowledge to solve the problem.	0	11	17	16	3
I prefer solving problems on my own.	1	5	6	22	14
We worked well together as a group.	23	16	5	4	0
We did not share the work out evenly in our group.	0	5	9	21	13
I found the group discussion helpful.	15	16	11	2	2
At the end, we were not sure we had the correct answer.	8	18	14	4	4
I could not have solved the problem by myself.	18	9	14	6	0
I needed the other group members to help me remember background information	11	22	11	2	1

The evidence from the above table indicates that most pupils felt the unit was difficult and completely new to them. Roughly, equal numbers were positive and negative in indicating enjoyment and satisfaction.

As responses to two open questions in the third version of the Endpiece, pupils expressed their opinions as listed:

Question 1: What did you need to know before you began?

Typical responses were:

(a) *how to write chemical equation or ion equation;*
(b) *understand the meaning of ionisation;*
(c) *how chlorine affects water;*
(d) *pH values or the pH table;*
(e) *acids and alkalis;*
(f) *element symbols and valences;*
(g) *how to read the graph and interpret it.*

Most of the comments were to do with equations and their interpretation.

Question 2: What made it difficult for you to solve the problem?

Typical responses were:

(a) *questions were worded in each away that they were not easy to read and understand;*
(b) *they had never done a problem like this before (no experience);*
(c) *it was completely new to them;*
(d) *too many chemicals;*
(e) *the problem was complicated;*
(f) *they have never heard of hypochlorous acid and some compounds before;*
(g) *they were not sure about ionisation equation;*
(h) *information on graph was confusing;*
(i) *hard to understand as some of the aspects they did not know, like compounds mixing with other ones;*
(j) *did not know a lot about pH.*

Here there is evidence of a wide diversity of responses. This reflects the nature of the problem which, although set in a context which was 'friendly', involved considerable amount of data and new ideas. In fact the problem is not really complicated but the pupils have to work through many ideas before they can see the key points.

6.3.3 Information from Tape Recordings

Although most groups were recorded, little of significance emerged from the recordings. Almost all could handle the problem without too much difficulty.

6.3.4 Analysis Summary

In this problem, the lack of confidence in a key procedure (the writing of ionisation equations) and, probably, a lack of understanding of the meaning of such equation, was major hurdle in seeking to solve the problem. Another feature that was very apparent was that, when faced with an amount of unfamiliar information, the inexperienced tend to be very unsure how to tackle the problem and how to pick out the key points.

6.4 *Unit 15*: Trees and Cars

The unit was used at the third data collection stage. Pupils were offered hints during the process of problem solving and discussions were tape recorded. In all, the total sample consisted of 33 (11 groups) S5 pupils. The main task of this unit is to check the quoted statement about trees and carbon dioxide which was emitted from a car. However, before starting it they were asking to write down a plan. It was also stressed to them that they could ask for hints if they are unsure what to do at any stage.

6.4.1 Pupils' Answers to The Unit

There are several ways to tackle the problem. To solve the problem, they have to complete a balanced combustion equation of octane and use it into the problem.

$$2\,C_8H_{18} \quad + \quad 25\,O_2 \longrightarrow 16\,CO_2 \quad + \quad 18\,H_2O$$

By observation and checking pupil answer sheets, almost all pupils did not make a plan prior to solve the problem. They just directly went straight into solving the problem. They appeared to start with what was familiar and move on, seeming to hope that the way forward would emerge. Only one group wrote a plan in the answer sheet. Because a sequence of hints was provided to them, most groups finally were able to gain correct answers. Only two groups failed to solve it. However, there were still some groups which did not ask for hints but reached a correct solution.

6.4.2 Hints Given to Pupils

Seven hints were provided to pupils and are shown in page 52. The most frequently used hint was Hint 2, given to 4 groups. Two other hints (Hint 4 and 5) were given to two groups. Hint 3 and 7 were given to one group individually.

6.4.3 Responses from Endpiece

This unit used the third version of the Endpiece which included thirteen closed questions and two open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed response to closed questions are shown in Table 6.5.

Table 6.5 Summary of Fixed Response Questions in Endpiece (Unit 15)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	0	17	15	1	0
The problem was difficult.	7	23	3	0	0
I found that solving this problem was satisfying.	8	12	10	3	0
The problem was completely new to me.	6	13	5	9	0
I learned nothing from the problem.	1	0	7	25	0
I had enough previous knowledge to solve the problem.	3	18	6	5	1
I prefer solving problems on my own.	3	3	7	13	7
We worked well together as a group.	6	13	12	1	1
We did not share the work out evenly in our group.	5	5	14	7	2
I found the group discussion helpful.	6	18	7	1	1
At the end, we were not sure we had the correct answer.	4	9	8	7	5
I could not have solved the problem by myself.	11	7	6	7	2
I needed the other group members to help me remember background information	5	12	7	8	1

Looking at this table, half of pupils (17 of 33) enjoyed solving the problem and felt that solving the problem was satisfying (20 of 33). Most pupils considered that the problem was difficult (30 of 33) but only half of them thought the problem was completely new to them (19 of 33) and said they had enough previous knowledge to solve the problem (21 of 33).

As the responses to the two open questions, pupils expressed their opinions which are listed:

Question 1: What did you need to know before you began?

Typical responses were:

(a) *how to write and balance chemical equation for combustion of octane (17)*
(b) *basic chemistry knowledge such as moles*
(c) *basic proportional skills to work out masses of substances*
(d) *how to do mole calculation and conversion*
(e) *how to unite balanced equations and mole calculations*
(f) *the formula masses of elements:hydrogen, oxygen and carbon*
(g) *the formula masses of octane and carbon dioxide*
(h) *basic arithmetic*

Obviously, most pupils understood that they needed to write a balanced combustion equation for the combustion of octane to reach the solution. They also pointed out that to do mole calculations and conversions were essential to success in solving the problem.

Question 2: What made it difficult for you to solve the problem?

Typical responses were:

(a) *did not know where to begin*
(b) *the statement at the beginning was quite confusing*
(c) *the extract from the newspaper made it difficult as the actual answer was very different to that stated in the newspaper*
(d) *bringing various parts of information and knowledge together*
(e) *having to work out all the different items such as how much petrol a car takes*
(f) *having to go through different stages and paths to find the solution, answers hidden in other answers*
(g) *too many problems to solve before starting and finding final solution*
(h) *converting all of the information and being able to link each part to another*
(i) *all the different information to use at one time*
(j) *the arithmetic involved was very tricky to grasp*
(k) *putting litres into mass (kg)*
(l) *we did not feel confident enough to solve the problem*
(m) *to find the number of moles of* CO_2.

The most difficulty pupils frequently encountered is to bring various parts of information and knowledge together, it has been shown at the above comments (d, e, f, g, h, i). In addition, they also felt the arithmetic was hard to grasp and manage. Some pupils were particularly confused about the answer when it involved a figure which was very different to the figure stated in the newspaper. In general, it was frequently observed that they did not know how to start off the problem. This must be seen alongside the apparent unwillingness in almost every group to consider planning before they started.

6.4.4 Information from Tape Recordings

Although most groups were recorded, little of significance emerged from the recordings. Almost all could handle the problem without too much difficulty.

6.4.5 Analysis Summary

One of the most interesting features to emerge from this unit was the unwillingness or inability of the pupils to discuss a plan despite the strong emphasis that this is what they should do. This is perhaps reflected in some of the difficulties that they listed as well as the observation that four groups asked for hint 2 which gave a key direction in order to make some progress in the unit. Tape recordings, their answer sheets and problem sheets all provided evidence that planning had not taken place. They just started with what they could do and then hoped that the way ahead would become apparent.

Chapter Seven

The Type 6 Problem

In this chapter, the data derived from type 6 problems are outlined and discussed. In such problems, the data are given, the method is unfamiliar and the goal is open, using Johnstone's classification (1993). Pupils have to make a decision about goals and choose an appropriate method in order to solve problem successfully. The following units were classified as the type 6 problem:

Unit 1: *Argon and Electric Welding*
Unit 4: *Fluoride Improves Tooth Decay?*
Unit 5: *The Glowing Splint Problem*
Unit 8: *Moving Gases*
Unit 10: *The Phosphorus Problem*
Unit 11: *The Leaking Pipe (not used in this project)*
Unit 13: *Solubility*
Unit 16: *Bonding*
Unit 17: *Chemicals from Salt (not used in this project)*

7.1 *Unit 1*: Argon and Electric Welding

This unit was used twice. Pupils were asked to find the chemical mistakes and look for a reasonable explanation from a newspaper report about a tragic industrial accident when electrical-welding was taking place. At the first data collection stage, 12 groups consisted of 36 (S3) pupils took part in solving it. In the light of their answers, it was found that the term "*electrical-welding*" was an obstacle for them. A clearer illustration about the nature of "*electrical-welding*" was added and used in the second data collection stage. The added information was "*welding where the heat to melt metal comes from an electrical spark*". 12 groups consisted of 35 pupils (early S3) participated in this stage and their discussions were tape recorded.

The main chemical mistake relates to argon which cannot be burned nor does it aid combustion. In addition, electric welding does not involve oxygen and the reason for using argon is to keep oxygen (from the air) away from very hot metal and reduce possibilities of metal oxidation. To avoid an accident, the workmen should wear the breathing apparatus in a closed container.

7.1.1 Pupils' Answers to The Unit

At the first data collection stage, almost all pupils (10 of 12 groups) were able to find the error that argon is a noble, unreactive gas and cannot be burned. Nevertheless, they thought there must be a hydrocarbon gas such as methane or butane being burned in the torch. These gases are good fuels and used up all the oxygen in the tank. Apparently, they did not understand the nature of "*electrical-welding*" and this led them to made a wrong connection with "*hydrocarbon*". As the hydrocarbon idea led them done a wrong approach, an extra illustration about "*electrical-welding*" was added.

7 (of 12) groups indicated that *carbon dioxide is a poisonous gas and killed the workmen*. It is true that when a hydrocarbon fuel is burned it will produce carbon dioxide (CO_2) but it is the lack of oxygen that is a more serious problem. A few groups have a more clear conception that if "*there lack of oxygen in tank, carbon monoxide was possibly produced which is even more poisonous than carbon dioxide*". Other groups' explanations also showed some misleading ideas. For instance, one group wrote "*the oxygen is used up by the flame, and the air is displaced by argon; the men could not take in argon and had no air to breathe, therefore suffocating*". They thought there was a flame since the welding was proceeding. Another group wrote "*it could not be argon as argon is unreactive and it is coloured, so the men would see it and escape*". In fact, argon gas is not coloured. Only one group noticed safety in the tank; they said: "*the workmen died from lack of oxygen because they did not use efficient breathing apparatus in an unventilated tank*". Only two groups stated that "*argon gas filled up the tank and took away (or pushed out) the oxygen*".

Looking at the working sheets, the following notes are found:

(a) *oxygen supports combustion*;
(b) *argon has a full outer shell, and so the oxygen is attracted to the element in order to get a completed outer shell*;
(c) *hydrocarbons (C 1 to C 4) are gases: must be methane, ethane, propane or butane;*
(d) argon may burn but does not react with oxygen;
(e) argon has full outer shell and so it is unreactive;
(f) fuel, oxygen and heat are needed for flame;
(g) argon does not burn, it is poisonous;
(h) workmen overcome by argon.

It is clear that most pupils have a basic knowledge about argon and hydrocarbons, even although hydrocarbons play no part in the actual problem. However, pupils did not seem to have a clear understanding about argon's behaviour. For example, while argon's lack of reactivity was noted by some, the possibility of burning or linking in some way to oxygen was not ruled out.

At the second data collection stage, it was found that pupils had not studied argon gas yet (the school had followed a different syllabus order) and most of them lacked knowledge of argon and understanding of elements and compounds. This was noted by observation and the comments from their teacher. Therefore, it was unlikely that they could see that argon would not burn with oxygen. The answers they made most were related to the flame (6 of 12 groups), such as "*the flame needed oxygen to burn and used up all the oxygen*", "*the flame and the sparks for the electrical-welding need oxygen to burn and so used up all the oxygen*". Only one group reached a correct answer. In addition, only one group mentioned that "*the workmen should not have been enclosed in the tank without an air vent or oxygen packs*". However, significantly, no one referred to "*hydrocarbon*" in their answers. The minor re-wording of the question might have helped but, again, they did not appear to have met hydrocarbons in their syllabus coverage.

Three groups thought that argon can be burned. A group pointed out that "*burning argon gas from the welders torch apparently used up all the oxygen*". Another group thought that "*a chemical reaction took place and the argon joined to make argon oxide compound and the men could not breath so they were suffocated*". Another group clearly did not understand: "*if the oxygen helps the argon gas burn, it acts as a catalyst and therefore is not used up*". This group understood "*pure oxygen is needed*" to burn and "*air has only 20% oxygen*", but they made an unclear and contradictory conclusion that "*when the argon burn in the air, the gas produced filled the tank and killed them*". One group simply pointed that "*the two men died of fumes because a small fire*".

Overall, the importance of previous knowledge, correctly grasped, is very apparent. In addition, previous knowledge inappropriately applied, can lead to wrong conclusions.

7.1.2 Responses from Endpiece

This unit used the first and the third versions of the Endpiece. The first version of the Endpiece included thirteen closed questions and eight open questions; the third version of the Endpiece included thirteen closed questions and two open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed responses to closed questions is shown in Table 7.1 and Table 7.2

Table 7.1 Summary of Fixed Response Questions in Endpiece (Unit 1 First Data Collection)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	0	9	18	4	5
The problem was difficult.	6	16	7	7	0
I found that solving this problem was satisfying.	1	21	5	5	4
The problem was completely new to me.	10	13	7	4	2
I learned nothing from the problem.	4	1	14	12	5
I had enough previous knowledge to solve the problem.	3	17	6	6	3
I prefer solving problems on my own.	2	3	9	11	11
We worked well together as a group.	13	9	4	5	5
We did not share the work out evenly in our group.	2	6	8	11	8
I found the group discussion helpful.	7	20	4	4	1
At the end, we were not sure we had the correct answer.	6	13	9	6	2
I could not have solved the problem by myself.	10	8	12	4	2
I needed the other group members to help me remember background information	8	17	6	1	4

Table 7.2 Summary of Fixed Response Questions in Endpiece (Unit 1 Second Data Collection)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	3	15	16	1	0
The problem was difficult.	10	17	2	6	0
I found that solving this problem was satisfying.	5	15	13	2	0
The problem was completely new to me.	11	15	5	4	0
I learned nothing from the problem.	0	5	8	15	6
I had enough previous knowledge to solve the problem.	6	12	10	6	1
I prefer solving problems on my own.	3	6	11	9	6
We worked well together as a group.	14	19	1	1	0
We did not share the work out evenly in our group.	3	0	2	17	13
I found the group discussion helpful.	13	15	6	0	1
At the end, we were not sure we had the correct answer.	5	18	6	4	1
I could not have solved the problem by myself.	10	9	6	9	1
I needed the other group members to help me remember background information	5	16	9	4	1

The sizes of the samples used in these two data collection stages were almost the same (36, 35). The two different groups views on enjoyment are statistically different (χ^2 = 9.5, df2, sig. at 1%). It is difficult to see why this difference could have occurred. Pupils in the first stage tended to be rather neutral while in the second stage, the pupils seemed to enjoy doing the problem (18 of 35) although they did not really understand much about argon gas. The difference may simply reflect the general attitudes of pupils in different schools, in the latter of which there appeared to be a very positive atmosphere.

In most other areas, there were no differences between the two groups in pupils views. However, fewer pupils in the second stage found the problem to be unsatisfying (2 of 35). This is consistent with their higher enjoyment and is perhaps related to the opinion that groups worked better in that stage ($\chi^2 = 8.1$, df2, sig. at 5%). Overall, pupils found the problem was difficult and new to them but felt they had enough knowledge to solve it. Groups worked well and they considered they needed each other to reach answers.

As the responses to **eight open questions in the first version of the Endpiece**, pupils expressed their opinions are listed:

For the following problems, there were no useful comments arising from them:

Question 1: *What did you do first to solve the problem?*
Question 2: *What was the second step?*
Question 4: *What was the easiest part in the problem?*
Question 7: *In what ways did working in a group help to solve the problem?*
Question 8: *What have you learned from the problem?*

Question 3: What did you need to know before you began?

Typical responses were:

(a) *what does burning methane do;*
(b) *hydrocarbons information (6);*
(c) *hydrocarbons producing carbon monoxide when burned without lots of oxygen;*
(d) *Fuels (4);*
(e) *argon is a noble gas and is very unreactive (13);*
(f) *argon does not burn, so it could not have caused the problem (4);*
(g) *The burning flame needs oxygen;*
(h) *the gases and their products and how they burned;*
(i) *general chemistry knowledge.*

Most pupils understood the properties of argon are important. Despite the complete absence of any mention of hydrocarbons, they also mentioned hydrocarbons and fuels that because they were not aware of the nature of "*electrical-welding*" and they developed a misleading linkage to their previous knowledge about combustion.

Question 5: What was a hindrance in preventing you from reaching a solution?

Typical responses were:

(a) *the fact that argon did not burn or react with anything, this put us back (5);*
(b) *what the argon did;*
(c) *where the argon came from;*
(d) *we were not sure which hydrocarbon it was (3);*
(e) *we were not sure which gas had been burned;*
(f) *which gas killed the men;*
(g) *whether or not the men suffocated or inhaled the gas;*
(h) *confusion (3);*
(i) *did not have enough useful knowledge to work with (5).*

It has been mentioned at section 6.2.2 that the question was slightly adjusted because of the word "*hindrance*". Indeed, pupils were aware that argon did not burn but were confused about what factor caused the men to die. The factor is that there was not enough oxygen in the closed tank and thus the workmen should use efficient breathing apparatus.

Question 6: How did you overcome obstacles in the problem?

> In general, most pupils stated that they overcame obstacles through "*group discussion*" or "*asked for help*". Only two groups mentioned that they "*used the Periodic Table*" to overcome obstacles.

As the responses to **two open questions in the third version of the Endpiece**, pupils expressed their opinions are listed:

Question 1: What did you need to know before you began?

Typical responses were:

- (a) *what happened if the gases (argon and oxygen) chemically join;*
- (b) *fire needs oxygen to burn;*
- (c) *gases used up oxygen in the air (3);*
- (d) *flames need oxygen to burn (3);*
- (e) *if argon could react easily with other chemicals or oxygen (4);*
- (f) *if argon was a flammable chemical (3);*
- (g) *oxygen helps things to burn (5);*
- (h) *argon does not burn with oxygen (2);*
- (i) *we need oxygen to breath (4);*
- (j) *what gases where being used or involved(3)*

They generally focused on the role of oxygen but did not address that the key factor is the property of argon. This was almost certainly because this topic had not yet been covered in normal teaching.

Question 2: What made it difficult for you to solve the problem?

Typical responses were:

- (a) *did not have enough information (7);*
- (b) *did not know a lot about argon (3);*
- (c) *the way the report was set out made it difficult to understand (3);*
- (d) *had a limit time (3);*
- (e) *it is difficult to concentrate with the microphone there;*

It is understandable that most pupils were puzzled by their lack of knowledge of argon.

7.1.3 Information fromTape Recordings

Although most groups were recorded, little of significance emerged from the recordings. Almost all could handle the problem without too much difficulty.

7.1.4 Analysis Summary

Evidently, if pupils are not aware of the nature of the electrical-welding, they cannot make an reasonable explanation for the tragedy. In looking at the overall pattern of data gathered, it is clear that absence of key knowledge greatly hinders successful problem solving. However, it is also evident that correct knowledge can be a hindrance if linked inappropriately. Although hydrocarbons are not mentioned in the problem, many groups in the first stage (where they had covered both noble gas chemistry and basic hydrocarbon chemistry) linked welding to the burning of hydrocarbons, putting the pupils down a line of thinking that was incorrect. In the second stage, neither topic had been covered and the wrong linkage was not made. This suggest an important pair of principles: for successful key knowledge is vital but knowledge linked inappropriately can be a hindrance.

7.2 *Unit 4:* Fluoride Improves Tooth Decay?

The unit was used at the first data collection stage with 15 groups (42 S3 pupils) taking part in solving it. Pupils were ask to find out as many errors as possible in a statement about tooth decay. The statement is "*Fluoride strengthens teeth by bonding with calcium, the main ingredient in enamel, to form calcium fluoride. Calcium fluoride is a harder, denser material than calcium alone, making teeth more resistant to the bacteria that cause decay*". Calcium, which not being the main ingredient (in terms of % of element present) is the main metallic element and can thus bond with fluorine to give a hard, ionic compound.

7.2.1 Pupils' Answers to The Unit

The possible errors existing in the statement are:

(a) *fluoride is a compound, it cannot bond with calcium again;*

(b) *fluoride does help reduce tooth decay, but not because it forms calcium fluoride but because it replaces the hydroxide ion in tooth enamel making the enamel less soluble and more resistant to bacteria. In fact, the main ingredient in tooth enamel* ($Ca_3(PO_4)_6(OH)_2$) *is not calcium but oxygen.*

However, pupils would not be expected to know any of this part (b).

Most groups (10 of 15) were able to differentiate between *fluoride* and *fluorine.* They pointed that it was fluorine strengthening teeth by bonding with calcium, not fluoride. However, there were still five groups which could not point out this error and made some incorrect answers. For example, one group said "*calcium and fluorine are both* *contained in liquid therefore can not be hard and can not be dense, calcium fluoride is not an anti-bacterial liquid so this can not prevent decay*". They seem misunderstood the reaction of calcium with fluorine and its function related to tooth decay. Others stated that: "*fluorine is a gas and calcium is a metal, calcium fluoride is denser so it could not prevent bacteria*" or "*for fluoride is a compound and could not bond with anything else so it would only mix with the element calcium, fluoride mixing with calcium would not make teeth more resistant to bacteria for calcium is not the main ingredient in enamel*". These comments illustrate some good ideas mixed with areas of confusion.

7.2.2 Responses from Endpiece

This unit used the first version of the Endpiece which included thirteen closed questions and eight open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed responses to closed questions is shown in Table 7.3.

Table 7.3 Summary of Fixed Response Questions in Endpiece (Unit 4)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	0	7	25	8	2
The problem was difficult.	11	25	6	0	0
I found that solving this problem was satisfying.	2	13	19	5	3
The problem was completely new to me.	18	19	1	4	0
I learned nothing from the problem.	4	9	11	16	1
I had enough previous knowledge to solve the problem.	1	7	17	13	4
I prefer solving problems on my own.	1	1	3	24	13
We worked well together as a group.	18	20	4	0	0
We did not share the work out evenly in our group.	1	2	6	22	11
I found the group discussion helpful.	8	26	6	0	1
At the end, we were not sure we had the correct answer.	16	19	4	2	1
I could not have solved the problem by myself.	8	18	13	1	2
I needed the other group members to help me remember background information	7	24	8	3	0

The evidence from the above table indicates that most pupils felt the problem was difficult and completely new to them. Over half of pupils (25 of 42) have a neutral response to the question about the problem being enjoyable. Only a few pupils (8 of 42) thought they have enough previous knowledge to solve the problem.

As the responses to **eight open questions in the first version of the Endpiece**, pupils expressed their opinions are listed:

For the following problems, there were no useful comments arising from them:

Question 1: What did you do first to solve the problem?

Question 2: What was the second step?

Question 4: What was the easiest part in the problem?

Question 7: In what ways did working in a group help to solve the problem?

Question 8: What have you learned from the problem?

Question 3: What did you need to know before you began?

Typical responses were:

(a) *bonding and teeth (12);*
(b) *things about chemical elements (12);*
(c) *the difference between elements and compounds;*
(d) *what the separate elements were (3);*
(e) *basic problem solving skill;*
(f) *what calcium and fluoride were (3).*

It is clear that the properties of elements and compounds is the most important area of knowledge needed to solve the problem.

Question 5: What was a hindrance in preventing you from reaching a solution?

Typical responses were:

(a) *did not have the background knowledge, such as calcium and fluoride (8);*
(b) *did not know about teeth (3);*
(c) *all the different words or names (3);*
(d) *the words I never understand (5);*
(e) *not enough information (10);*
(f) *the part about calcium fluoride density threw us off track;*
(g) *did not know a lot about the issue (3);*
(h) *arguing on answers (5);*
(i) *did not know what to do.*

Obviously, the big hindrance is that they were not given enough information about teeth.

Question 6: How did you overcome obstacles in the problem?

Similar to other units, the common methods were "*group discussion*", "*shared knowledge among the group*" or "*asked for help*".

7.2.3 Analysis Summary

Areas of unfamiliarity caused confusion, including less familiar terminology (like density) and their lack of knowledge about teeth and their constitution. The issue of bacterial attack of teeth sometimes side-tracked the discussion. However, the most important observation is that, where there is a lack of a clear grasp of the concepts of elements, compounds and bonding, then pupils started to generate explanations which mixed error with truth. This, perhaps, points to an important aspect of problem solving: where key concepts are partially grasped, then approaches to problem solving will be confused and the problem solver will not even be aware of the confusion.

7.3 *Unit 5:* The Glowing Splint Problem

The unit was used twice. At the first data collection stage, 10 groups consisting of 30 (S3) pupils took part in solving it. The unit at this stage was in two parts. In part 1, pupils were asked to solve 4 questions about nitrogen dioxide (NO_2) which is formed in a car engine. These questions are listed below:

(a) *Explain how the gas nitrogen dioxide (NO_2) is formed in a car engine.*
(b) *What problems can NO_2 cause?*
(c) *How can the problem of NO_2 be solved in a car?*
(d) *When the NO_2 is removed from the car exhaust, what gases are formed?*

The reason for the inclusion of these questions is to foster in pupils an association with the idea of "catalyst" and apply it to solve the part 2 problem. In part 2, results of experiments were provided showing that a glowing splint could be re-kindled by pure oxygen not by NO_2 or air. On the other hand, in another experiment, a glowing splint could be re-kindled by the mixture of NO_2 and O_2 (the proportion of oxygen is 20%, same as the air) which was generated from breaking up copper (II) nitrate. The full unit is shown in Appendix A. Pupils have to try to explain this unexpected result.

The initial objective is that pupils should be able to use the idea of "catalyst" to make a reasonable explanation. The evidence of results showed that many groups understood that using a catalytic converter can reduce the problem of NO_2 but did not know NO_2 can be decomposed into N_2 and O_2 by the catalyst. Not surprisingly, they were also not able to provide a reasonable explanation about the unexpected result. Therefore, it was considered that the unit had to be slightly adjusted to provide a more clear illustration in order to lead pupils to apply the concept of "catalyst' effectively. Thus the four questions in part 1 were removed and replaced by another simplified question:

When the NO_2 is broken up in the exhaust, what gases are formed?

This focussed the attention of pupils on the products formed. The part 2 problem remained unchanged and was used at the third data collection stage. 10 groups consisting of 27 (S4) pupils took part in this stage of test, their discussion were tape recorded. In the first stage, S3 pupils were used late in the year while, in the second stage, S4 pupils were used early the following session. It was thought that this would provide a fair comparison.

7.3.1 Pupils' Answers to The Unit

For S3 pupils (at the first data collection stage), almost all pupils obtained quite correct answers to the part 1 questions (a), (b) and (c). They knew that nitrogen reacts with oxygen in a car engine to form nitrogen dioxide. In addition, they were also aware that nitrogen dioxide can cause acid rain and pollution which will damage environment and harm human beings. To reduce the problem of NO_2 in a car, they stated that it could be solved by using catalytic converter or using a different petrol like diesel fuel. Nevertheless, astonishingly, several groups (5 of 10) mentioned that "*carbon dioxide, carbon monoxide or sulphur dioxide*" are formed when NO_2 is removed. One group thought that "*lead vapour is formed when NO_2 is removed*". Although they knew the function of "*catalytic converter*" in the car engine, they seem did not understand that nitrogen dioxide (NO_2) can be decomposed to N_2 and O_2 and this led them to draw the incorrect solutions. Only two groups clearly pointed that nitrogen and oxygen are formed when NO_2 is removed.

In part 2, most pupils were able to point out that the experimental result is unexpected because the products have the same amount of oxygen (20%) as in air but will re-kindle a glowing splint. Referring to a possible explanation for the result, only one group reached the solution that "*a catalyst breaks up the nitrogen dioxide into nitrogen and oxygen which gives more oxygen to relight the glowing splint*". Although five groups gave a plausible explanation that "*nitrogen dioxide contains oxygen, there is more than 20% oxygen presented*", they just simply added the oxygen from nitrogen dioxide to the 20% oxygen but did not appear to appreciate that NO_2 gas has to be decomposed.

For S4 pupils (at the third data collection stage), most of them correctly answered the modified question that "*when NO_2 is broken up it breaks up into nitrogen and oxygen*". Similarly, most pupils were also able to explain why the the experimental result is unexpected. However, two groups focused on "*nitrogen dioxide*" instead of "*oxygen*". They said "*in experiment 1, it shows that nitrogen dioxide does not rekindle a glowing splint but in experiment 2, it does rekindle a glowing splint so the result is unexpected*". They seem to forget that the main influential factor is the percentage of oxygen although nitrogen dioxide is still involved in it. This time almost all pupils could make more clear explanation about the unexpected result. They mentioned the "*heat*" or "*catalyst*" will help breaking up nitrogen dioxide into N_2 and O_2. Some of the explanations were accurate such as "*the heat from the glowing splint breaks down nitrogen dioxide into nitrogen and oxygen producing enough oxygen to relight the glowing splint*" or "*the glowing splint acts as a catalyst and to break up nitrogen dioxide to release more oxygen to relight the glowing splint* ". It seems that removal of irrelevant information and adding a pertinent question to the problem is more helpful. Making the specific link between catalysis and the formula of the gases seems to be critical.

7.3.2 Responses from Endpiece

This unit used the first and the third version of the Endpiece. The first version of the Endpiece included thirteen closed questions and eight open questions; the third version of the Endpiece included thirteen closed questions and two open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed responses to closed questions is shown in Table 7.4 and Table 7.5

Table 7.4 Summary of Fixed Response Questions in Endpiece (Unit 5 First Data Collection)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	0	6	4	16	4
The problem was difficult.	13	11	3	2	1
I found that solving this problem was satisfying.	0	10	10	8	2
The problem was completely new to me.	4	5	5	13	3
I learned nothing from the problem.	1	3	8	16	2
I had enough previous knowledge to solve the problem.	2	12	12	3	1
I prefer solving problems on my own.	1	2	2	10	15
We worked well together as a group.	8	14	2	4	1
We did not share the work out evenly in our group.	4	4	10	6	6
I found the group discussion helpful.	5	16	7	1	0
At the end, we were not sure we had the correct answer.	15	9	1	3	2
I could not have solved the problem by myself.	9	8	2	8	3
I needed the other group members to help me remember background information	8	8	9	3	2

Table 7.5 Summary of Fixed Response Questions in Endpiece (Unit 5 Third Data Collection)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	3	17	6	1	0
The problem was difficult.	7	11	4	4	1
I found that solving this problem was satisfying.	9	11	6	0	1
The problem was completely new to me.	3	15	8	1	0
I learned nothing from the problem.	2	0	2	20	2
I had enough previous knowledge to solve the problem.	3	12	8	2	2
I prefer solving problems on my own.	1	0	7	13	6
We worked well together as a group.	11	14	2	0	0
We did not share the work out evenly in our group.	0	1	9	8	9
I found the group discussion helpful.	8	17	1	1	0
At the end, we were not sure we had the correct answer.	3	8	3	8	5
I could not have solved the problem by myself.	6	7	9	3	2
I needed the other group members to help me remember background information	3	14	6	3	1

In comparing the two groups, it is interesting to note that the second group found the problem was more enjoyable ($\chi^2 = 16.7$, df1, sig. at 0.1%) and more satisfying ($\chi^2 = 9.5$, df1, sig. at 1%) despite finding the material less familiar ($\chi^2 = 7.7$, df1, sig. at 0.1%) than the first group. The last observation may reflect on different coverage of the syllabus but it does appear that the modification of the unit to specifically link catalysis to the products formed enabled the pupils to respond to the unit in a more positive way. In most other areas, there is no different between the groups although, interestingly, the first group were more sure that they had the right answer ($\chi^2 = 9.2$, df1, sig. at 1%) even though, in fact, less of them did achieve the correct answer.

As the responses to **eight open questions in the first version of the Endpiece**, pupils expressed their opinions are listed:

For the following problems, there were no useful comments arising from them:

Question 1: *What did you do first to solve the problem?*
Question 2: *What was the second step?*
Question 4: *What was the easiest part in the problem?*
Question 7: *In what ways did working in a group help to solve the problem?*
Question 8: *What have you learned from the problem?*

Question 3: What did you need to know before you began?

Typical responses were:

(a) *about NO_2: the effects of NO_2 on the environment and how NO_2 is formed (11);*
(b) *about car engines: how an engine worked, what happens in a car engine (10);*
(c) *about catalysts and fuels (3);*
(d) *acid rain;*
(e) *car exhaust fumes.*

It seems to be easy to focus on the main concept of "*NO_2*" and "*car engines*" but no one seemed to associate the catalyst with NO_2.

Question 5: What was a hindrance in preventing you from reaching a solution?

Typical responses were:

- *(a) did not have enough knowledge (4);*
- *(b) the problem was too difficult (7)*
- *(c) not understood the answers to the questions;*
- *(d) conflicting ideas;*
- *(e) lack of time;*
- *(f) concluding how the engine worked;*
- *(g) working out NO_2 involvement with cars.*

The most serious hindrances they suggested were: *the problem was too difficult* and *they did not have enough knowledge*. They seemed to have an understanding of the idea of a catalyst but failed to apply this to the problem.

Question 6: How did you overcome obstacles in the problem?

> Some pupils (7 of 30) said they did not overcome obstacles and "*guessed*" it. Most pupils (15) have the same responses: "*discussed the possible answers*".

As the responses to **two open questions in the third version of the Endpiece**, pupils expressed their opinions as listed:

Question 1: What did you need to know before you began?

Typical responses were:

- *(a) what a catalyst is and how catalyst works; how catalyst can speed of reactions (9);*
- *(b) about converter or catalyst in car exhaust (4);*
- *(c) how to break up compounds (4);*
- *(d) basic chemistry knowledge (5);*
- *(e) the symbols of different elements;*
- *(f) how equation works.*

The basic knowledge is the properties of catalyst and how compounds will be broken up by it.

Question 2: What made it difficult for you to solve the problem?

Typical responses were:

(a) *where the extra oxygen came from;*
(b) *did not know much about cracking and the experiment (3);*
(c) *did not realise a catalyst was involved in the experiment;*
(d) *the way the question was set up;*
(e) *not being totally confident we knew the answer;*
(f) *had never done a problem like this before;*
(g) *finding out what could be the catalyst in the reaction (3);*
(h) *not remembering about car exhausts and the breaking-up of substances(3);*
(i) *not knowing about the catalyst (3);*
(j) *it was difficult to put all the information into an answer paper.*

The range of issues raised by pupils illustrates that the number of ways the approached the problem are very varied. It is consistent with the observation that pupils do not plan how to solve problems. They seem to start with whatever is familiar, - content, procedures, concepts. They try approaches in several directions, hoping for some insight to emerge that will point them to the way forward.

7.3.3 Information from Tape Recordings

Although most groups were recorded, little of significance emerged from the recordings. Almost all could handle the problem without too much difficulty.

7.3.4 Analysis Summary

It is clear that the revised version produced much greater success in solving the problem and that the specific linking of the catalysis with the breakdown of nitrogen dioxide was the key element in allowing success. In some way, the first group were unable to make this linkage and were seriously hindered in solving the problem. This is consistent with the hypothesis that, usually, learners cannot make linkages between key concepts: the links must be suggested or supplied by the teacher in some way.

7.4 *Unit 8*: Moving Gases

The unit was used twice. The experimental data about five gases and the distance travelled are given in a table (Table 7.6, overleaf), pupils were asked to spot any pattern in these results and test whether their pattern was correct or not. In addition, under the same conditions they are also asked to predict the distance a sixth gas (Cl_2) would travel. At the first data collection, 12 groups, consisting of 35 (S4) pupils, took part in solving it. It was expected that pupils could relate the distance travelled with the formula mass.

Table 7.6

Gas	Distance (cm)
SO_2	50
HCl	66
CH_4	100
SO_3	44
NH_3	94

Table 7.7

Gas	Distance (cm)
SO_2	50
CH_4	100
HCl	66
SO_3	44
NH_3	94

As a result, most pupils were able to point out the pattern that the heavier the molecule is, the less distance it would travel but no group was able to spot the pattern exactly: that the distance travelled has the inverse square relationship with the formula mass. Therefore, a hint (*an extra thing to think about......can you find a more exact relationship between the mass of the molecule and the distance moved?*) was provided and the unit was revised by changing the order of the gases travelled distance (Table 7.7), where the order of the distances of SO_2 and CH_4 were changed, to test whether pupils can reach a more exact answer. Afterwards, it was used at the second data collection stage, 14 groups consisted of 38 (S4) pupils participated in this stage of test, their discussion were tape recorded.

7.4.1 Pupils' Answers to The Unit

Most pupils in the first data collection stage understood that the lighter the gas is the further it travels. By checking the notes on their working sheets, these groups did calculate the formula mass of gases but did not write it into the answer . However, some groups referred to the term "*mass*" but did not precisely link it to "*formula mass*". They often connected it to "*atomic mass*". This can be seen from the selected excerpts: "*the higher the atomic mass, the less distance the gas travels*" and "*the lower the relative atomic masses the more distance travelled*". The answers were not completely incorrect but it just appears that pupils were not thorough in their analysis of the problem. Only one group clearly stated that "*we tried to relate gram formula mass to distance travelled*". In addition, one group linked the presence of Oxygen atoms with shorter distance. They said: "*sulphur plus oxygen compounds travel between 44 and 50; the more oxygen contained in the compound the less distance travelled*".

For the question "*how would you test to see if your pattern is correct?*", half (6 of 12) groups suggested that they can use other different gases and measure the travelled distances to examine their idea. The other six groups did not answer this question or they gave an incorrect suggestion. Referring to the question "*how far the chlorine gas would travel*", the most accurate answer is 48 cm. Three groups employed the masses of SO_2 and SO_3 and compared with chlorine to obtain a correct answer. One group wrote "*the atomic mass of chlorine is 71 which higher than SO_2 and lower than SO_3, so it had to be in the middle because the difference is 16. Chlorine travels at 47 cm*". Two other groups had a similar answer that "*Cl_2 will travel between 50 cm and 44 cm, because it* *was lighter than SO_3 (80) which travelled 44 cm and heavier than SO_2 (64) which travelled 50 cm*". However, only one group drew a rough graph to obtain their answer (47.4 cm).

At the second stage, almost all pupils obtained similar patterns: "*the lighter the gas the further the distance it may travel*" or "*as the molecular mass increases the distance travelled decreases*". Only one group particularly considered that the different kinds of atoms (H, O and S) would influence the gas travelled distance. They stated that "*the gas with hydrogen travels the furthest because it is the lightest; the gases with sulphur and oxygen in them travel the least because they are two of the heaviest* ". Disappointingly, no group could find a further definite conclusion through the comparison between SO_2 and CH_4 although these two gases have been moved to be adjacent. Only one group noticed the relationship between the travelled distances of SO_2 and CH_4 but they were still unable to draw a conclusion clearly. Their answer was "*if there is a di-oxygen in the formula* (they meant SO_2) *then it would be half in methane*".

To test whether the pattern they made is correct, half (7 of 14) of groups knew that they can examine their ideas by using different gases. Two groups' methods were unreasonable because they forgot the given gases are poisonous (like SO_2) which cannot be used directly in an opened room. These methods were:

(a) "*the gases are perfumed* (presumably they meant a smell) *so if you put a gas at one end of the room and timed how long it takes for you to smell it, then you could find out which gas travels the quickest*";

(b) "*line people at 40 cm, 50 cm, 60 cm, 70 cm, 80 cm, 90cm and 100 cm away from the gas, let off each gas after each other wait until the last about 25cm*".

Only one group thought that the oxygen and hydrogen might be the main factors which would result in the difference of travelled distance. Their description was: "*the experiment would be done again with oxygen and hydrogen to see if O_2 and H_2 are the causes of the distance travelled*". For the travelled distance of Cl_2, only 4 groups obtained an approximately accurate answer. In this part, pupils' performances were worse than those in the first stage.

7.4.2 Responses from Endpiece

This unit used two versions of the Endpiece. The first version of the Endpiece included thirteen closed questions and eight open questions; the second version of the Endpiece included thirteen closed questions and six open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed responses to closed questions is shown in Table 7.8 and Table 7.9

Table 7.8 Summary of Fixed Response Questions in Endpiece (Unit 8 First Data Collection)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	3	8	12	6	6
The problem was difficult.	11	16	6	2	0
I found that solving this problem was satisfying.	1	11	12	6	5
The problem was completely new to me.	6	20	6	3	0
I learned nothing from the problem.	5	1	10	12	6
I had enough previous knowledge to solve the problem.	2	6	10	9	8
I prefer solving problems on my own.	0	2	7	13	13
We worked well together as a group.	12	16	4	2	1
We did not share the work out evenly in our group.	2	3	4	18	8
I found the group discussion helpful.	3	19	7	4	1
At the end, we were not sure we had the correct answer.	7	10	8	8	2
I could not have solved the problem by myself.	7	12	8	5	2
I needed the other group members to help me remember background information	5	13	11	3	2

Table 7.9 Summary of Fixed Response Questions in Endpiece (Unit 8 Second Data Collection)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	1	23	11	2	1
The problem was difficult.	8	17	11	2	0
I found that solving this problem was satisfying.	1	18	12	7	0
The problem was completely new to me.	18	17	1	2	0
I learned nothing from the problem.	1	5	9	18	5
I had enough previous knowledge to solve the problem.	0	11	17	9	1
I prefer solving problems on my own.	2	3	8	19	6
We worked well together as a group.	11	19	7	1	0
We did not share the work out evenly in our group.	0	4	5	22	7
I found the group discussion helpful.	8	23	4	3	0
At the end, we were not sure we had the correct answer.	4	17	9	7	1
I could not have solved the problem by myself.	10	12	9	7	0
I needed the other group members to help me remember background information	3	15	12	5	3

The only difference between the two versions of the unit was in the layout of the table and, as might be expected, there were few differences between the two groups. The second group found the problem was more enjoyable ($\chi^2 = 7.3$, df1, sig. at 1%) and also were more definite that the problem was new to them ($\chi^2 = 4.2$, df1, sig. at 5%), this latter difference probably being a reflection of the syllabus coverage in the school.

As the responses to **eight open questions in the first version of the Endpiece**, pupils expressed their opinions are listed:

For the following problems, there were no useful comments arising from them:

Question 1: What did you do first to solve the problem?
Question 2: What was the second step?
Question 4: What was the easiest part in the problem?
Question 7: In what ways did working in a group help to solve the problem?
Question 8: What have you learned from the problem?

Question 3: What did you need to know before you began?

Typical responses were:

(a) *how to find the relative atomic mass (9);*
(b) *how to calculate the masses (9);*
(c) *about some knowledge of gases;*
(d) *molecule formula;*
(e) *little about particle movement;*
(f) *the lighter the gas, the further it will travel.*

Apparently, pupils seem to understand that the relative atomic mass is an important factor.

Question 5: What was a hindrance in preventing you from reaching a solution?

Typical responses were:

(a) *did not explain clearly how to make a conclusion and no examples were given (3);*
(b) *could not figure out the patterns at first (3);*
(c) *finding the link between formula and distance;*
(d) *comparing the gases did not always give us the answer we were looking for;*
(e) *lack of resources to work from;*
(f) *trying to work out what to do;*
(g) *how to test our theory;*
(h) *it was quite difficult and hard;*
(i) *the math calculation at the end.*

It showed that they did not know how to start out the problem and the lack of a familiar method seems to have puzzled them. These responses suggest that they were very uncertain how to tackle the problem. This entirely understandable in that the problem was totally new to them and there as no clear goal.

Question 6: How did you overcome obstacles in the problem?

The general responses were: "*did not overcome*", "*help from other members or teacher*" and "*by team work*". Only a few pupils pointed that they looked at information carefully.

As the responses to **six open questions in the second version of the Endpiece**, pupils expressed their opinions as listed:

Question 1: After reading the problem, what did your group discuss first?

Typical responses were:

(a) *the gas and distance table first (3);*
(b) *the relative atomic mass and the distance (4);*
(c) *trying to find out what the pattern would be (11);*
(d) *have to find out the GFM (gram formula mass) for each gas (3);*
(e) *the distance the different gases travelled;*
(f) *the number of hydrogen and oxygen in each gas;*
(g) *the connection of the weight of the molecules with the distance they travelled;*
(h) *the adding up of relative atomic mass.*

To find out what the pattern would be, the underlying point is the relationship of the formula masses of gases with the travelled distance.

Question 2: What was the second step your group took to solve the problem?

Typical responses were:

(a) *look for a pattern (5);*
(b) *worked out the relative atomic masses of the different gases (7)*
(c) *to check whether the pattern was correct which we had chosen (5);*
(d) *work out the molecular mass / formula weight (5);*
(e) *did the GFM and compared them with the distance the gas travelled at;*
(f) *try to work out the pattern by looking at the distance and gas formula.*

The approaches they took are similar as those in question 1.

Question 3: What did you need to know before you began?

Typical responses were:

(a) *knowledge about how to find out one mole of a gas (3);*
(b) *relative atomic masses or gram formula masses (GFM) of the gases (15);*
(c) *what the problem was;*
(d) *how to work out formula weight (4);*
(e) *the names of the different atoms;*
(f) *the symbols for the elements or compounds;*
(g) *what the problem was about;*
(h) *the weight of the molecules and the distance they travelled.*

There are two messages: one is the relevance of GFM; another is how to calculate GFM.

Question 4: What made it difficult for you to solve the problem?

Typical responses were:

(a) *we could not see the connection at first (3);*
(b) *there was no introduction of what you were trying to find;*
(c) *we were not told even a little about what to do;*
(d) *we did not know exactly where to look for the answer;*
(e) *I had never seen it before;*

(f) *it was unexpected to me;*
(g) *it was difficult to spot the pattern (4);*
(h) *not being able to work out the main problem straight away;*
(i) *we were not sure what experiment we could do to see if the pattern was correct;*
(j) *the distance were in no particular order*
(k) *there was no obvious pattern before beginning.*

Obviously, because the method is unfamiliar to them and goal was open they felt this problem was difficult and needed a clear instruction to help them solve it.

Question 5: How did you overcome obstacles in the problem?

The most frequent comments they made were: "*discuss with the group*" or "*worked together and combined all ideas*".

Question 6: What do you think you learned from trying to solve it?

Typical responses were:
(a) *the lighter the molecule the more distance it travels;*
(b) *we found out that gases with higher GFM went less in distance and the ones with lower GFM it went further in distance (4);*
(c) *working in a group is a lot more helpful than trying to do it by myself (3);*
(d) *it is always good to have somebody to discuss with;*
(e) *the other two people in my group are better at this kind of thing than I am;*
(f) *I was able to work in a group to solve different types of problems;*
(g) *I learned it is easier solving problems in a group (6);*
(h) *I learned that not everything can be solved individually sometimes you need help;*
(i) *I have learned look for other ways of doing it than just one way.*

By solving the problem, they have learned two things. One is about the chemistry knowledge; another is about the advantages of working in group.

7.4.3 Information from Tape Recordings

Although most groups were recorded, little of significance emerged from the recordings. Almost all could handle the problem without too much difficulty.

7.4.4 Analysis Summary

Although the methods required to reach solutions were well within the grasp of all pupils, there is clear evidence that the uncertain goal left most groups in an uncertain situation at the outset. Nonetheless, they tended to start with familiar territory by looking at formula masses and they recognised the great advantage in working with others in seeking to find a solution. The modification of the unit was introduced to test if, by bringing together two key pieces of information (where the formula masses related easily to each other in a simple way), pupils would find answers more readily. This was not observed. Surprisingly, the juxtaposition of the information that pointed to the pattern made no difference to the performance.

7.5 *Unit 10*: The Phosphorus Problem

The main task of this unit is to obtain pure phosphorus from rock phosphate [$3Ca_3(PO_4)_2.CaF_2$]. It links to the pre-Standard Grade curriculum: separation of mixtures. Pupils are given tabulated information about the four products ($CaSiO_3$, CO, P_2 and SiF_4) from the industrial process. It is assumed that pupils would be able to separate the mixtures by taking advantage of the different physical and chemical properties. Therefore, the unit was used for S3 pupils at the second data collection stage. 12 groups consisted of 35 pupils took part in solving it and their discussions were tape recorded.

Unfortunately, it was observed that there were six barriers prevented them from reaching a solution. These barriers were:

(a) *not sure what to do at outset, needed hints;*
(b) *unfamiliar molecules;*
(c) *not understand the symbol of "~";*
(d) *neglect sign for temperature;*
(e) *not sure how to use the table of information;*
(f) *lack of confidence.*

Despite the very simple basis of the problem, only three groups obtained partly correct answers. In fact, the unit is not easy to solve in that four unfamiliar compounds are involved with the actual method of separation being quite subtle. In the light of observation and their written answers, the unit seems to be too difficult for S3 pupils, thus it is considered that the unit might be more suitable for S4 or S5 pupils.

7.5.1 Pupils' Answers to The Unit

To obtain the pure phosphorus solid, pupils have to look at the given information carefully. Looking at the melting and boiling points shows clearly that, with very slight cooling, the calcium silicate ($CaSiO_3$) solidifies leaving the others as gases. The subsequent step is to cool these three gases in water at a temperature above 44 °C (in fact at 70 °C). At this temperature, the phosphorus stays as a liquid and can be separated readily from the solid silicon dioxide and the CO gas which passes through. After the silicon dioxide is removed, the water is allowed to cool and the solid phosphorus forms under the water. Although the water contains dissolved hydrogen fluoride, which derives from the reaction of SiF_4 with water, this does not contaminate the solid phosphorus.

Only three groups of pupils were able to draw out a seemingly reasonable approach. Their answers were partly correct and are listed below:

(1) *to get pure phosphorus we would cool the three gases to 44 °C, the other two gases would escape into the atmosphere. We would then cool the phosphorus under water about 30 °C degrees and put a small jar under the water to scoop up the solid, from here you would put this in a glove box, open the jar and let the phosphorus and the water out to let the solid dry off.*

(2) *Mix four compounds with water, then*
SiF_4: Reacts in water,
CO: Escapes as a gas in water,
P_2: Changes to a liquid, lies in bottom of melt. Cool water under 44 °C.(it turns to crystals, lies at bottom of water.)
Keep P_2 under water as when it is taken out of water it will explode.
$CaSiO_3$: no reaction.

(3) *Put it under water and you would get rid of SiF_4 and left with two compounds (CO + P_2). When CO escapes, then you cool down P_2 as a liquid and it turns into a solid.*

Other pupils were unable to discover the significantly useful data and use them to solve the problem. They tended to see the items of information as discrete entities and were unable to bring together several items to make a coherent pattern. It seems to be difficult for them to bring pieces of information together and employ them logically. For instance, one group wrote a note: "*put SiF_4 in water to make it disappear*" then they separate other compounds by "*melt at -90 °C, then boil at 280 °C, then boil at -191°C, then melt at ~1540 °C* ". Another group's answer was "*to separate $CaSiO_3$ from the gases you would use the method of filtration; P_2 by using centrifuge*". In practice, they have learned the methods of separation such as "*filter*" or "*using centrifuge*" but just could not manage to operate these methods in a meaningful way. The other 7 groups have similar mistakes and confusions.

7.5.2 Responses from Endpiece

This unit used the third version of the Endpiece which included thirteen closed questions and two open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed responses to closed questions is shown in Table 7.10.

Table 7.10 Summary of Fixed Response Questions in Endpiece (Unit 10)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	4	11	8	10	2
The problem was difficult.	21	9	4	0	1
I found that solving this problem was satisfying.	5	12	11	5	2
The problem was completely new to me.	19	11	3	2	0
I learned nothing from the problem.	1	4	5	13	12
I had enough previous knowledge to solve the problem.	2	11	4	13	5
I prefer solving problems on my own.	1	5	11	8	10
We worked well together as a group.	15	14	4	2	0
We did not share the work out evenly in our group.	0	3	0	21	9
I found the group discussion helpful.	11	16	6	2	0
At the end, we were not sure we had the correct answer.	14	13	2	2	4
I could not have solved the problem by myself.	17	11	3	1	3
I needed the other group members to help me remember background information	12	13	7	3	0

It can be seen from the table that most pupils (30 of 35) felt the problem was difficult and completely new to them although many seemed to enjoy it and found it satisfying. The success of group work was particularly marked. According to their responses, it is understandable that there was no group could reach a completely correct solution because the problem was difficult and unfamiliar.

As the responses to two open questions in the third version of the Endpiece, pupils expressed their opinions are listed:

Question 1: What did you need to know before you began?

Typical responses were:

(a) *methods of separation (11);*
(b) *what each symbol means (3);*
(c) *knowledge on phosphorus and other chemicals (4)*
(d) *names of chemicals like SiF_4 is silicon fluoride;*
(e) *what the chemical formulas were;*
(f) *the given four physical and chemical properties;*
(g) *freezing point of water.*

The methods of separation was addressed that it was essential. The knowledge on phosphorus and other chemicals also play an important role.

Question 2: What made it difficult for you to solve the problem?

Typical responses were:

(a) *I could not remember the methods of separation (3);*
(b) *they all had different melting points, boiling points and reactions;*
(c) *how to separate P_2 and $CaSiO_3$ and gases(4);*
(d) *it is difficult to separate gases;*
(e) *we had never done anything as complicated before (6);*
(g) *it had a lot information to take it;*

(h) *compounds and information were new to me;*
(i) *all the scientific elements and chemicals (3);*
(j) *not enough information.*

It is very difficult for them to solve the problem because they were unfamiliar with the method and the chemicals. This seems to reflect working memory space overload.

7.5.3 Information from Tape Recordings

Although most groups were recorded, little of significance emerged from the recordings. Almost all could handle the problem without too much difficulty.

7.5.4 Analysis Summary

On the surface, this unit appears to rely on very simple ideas. However, there is considerable amount of data and it is necessary to being this data together to reach meaningful conclusions. There is also a difficulty that, in all their experience of separating mixtures, they have never faced a mixture at high temperature where the answer involves controlled cooling, use of a solvent (water) within a temperature range, along with filtration and further cooling. The problem also involves materials in gas, liquid and solid states. Many ideas have to be brought together from long term memory and, at the same time, the amount of data to be considered is large. It is not perhaps surprising that success was limited.

7.6 *Unit 13*: Solubility

The unit was used twice. At the first data collection stage, 12 groups consisting of 34 (S4) pupils took part in solving it. The unit at this stage was in four parts. The solubility of a large number of compounds are shown in a table (see Appendix A). A definition of solubility is also provided. Firstly, pupils had to draw out the patterns of solubility. Secondly, they had to predict what might happen when a solution of magnesium chloride ($MgCl_2$) was mixed with a solution of potassium hydroxide (KOH). The third part was to work out a way to obtain a solution containing only sodium nitrate from a solution which contains a mixture of lead nitrate ($Pb(NO_3)_2$) and sodium nitrate ($NaNO_3$). Finally, by using the given information, they had to predict the approximately solubility for strontium hydroxide and strontium sulphate. Pupils had not met solubility rules before.

It was expected that pupils could group pieces of information and make a definite pattern which could be applied. However, the evidence from their answers revealed that most pupils were able to draw simple solubility rules but could not apply these to answer the other three parts successfully. It was considered that too many tasks were being required of pupils (pupils said they did not have enough time) and the unit was revised: part 3 was removed and the orders of the remaining part 2 and 4 were rearranged. Afterwards, the revised version was used at the second data collection stage. 5 groups consisting of 14 pupils participated in this stage of test and their discussions were tape recorded.

7.6.1 Pupils' Answers to The Unit

Most pupils (10 of 12 groups) were able to draw out the solubility rules. Some rules they established were clear and organised such as "*sodium and potassium are always soluble*", "*the alkali metals are soluble in all compounds*", "*$CO_3{}^{2-}$ is insoluble except with alkali metals*" or "*all nitrate are soluble*". Nevertheless, a few groups still did not develop the rules on a wide basis. They drew the solubility patterns simply stemmed from a single piece of data: "*top two lines are soluble*", "*Na^+ is always soluble*", "*all K^+ are soluble*" or "*every sodium is soluble*". In fact, sodium and potassium can be grouped together as they are alkali metals. In part 2, when the solution of magnesium chloride ($MgCl_2$) is mixed with the potassium hydroxide (KOH) solution, the solid magnesium hydroxide [$Mg(OH)_2$] will be formed. Only one group obtained the correct answer and offered a reaction equation. Three groups made incorrect answers while the other eight groups did not answer the problem at all.

In part 3, only three groups developed an appropriate method to obtain sodium nitrate. One group stated that they would add "*hydroxide solution*" into the mixture of solution so that the sodium would dissolve; another two groups pointed out that they would add "*sodium carbonate*" into the solution and "*carbonate would react with lead and form a solid*". The other groups did not answer this problem but it is possible that this might be due to the lack of sufficient time. In part 4, several groups' responses were "*strontium hydroxide is slightly soluble, strontium sulphate is slightly insoluble*". Apparently, they did not look at the problem carefully or might not know how to solve the problem which led them to a vague answer. In addition, three groups who tried to work out an approximately solubility also failed.

At the second data collection stage, it was found that pupils demonstrated similar characteristics in solving the part 1. Three groups drew the solubility patterns which also stemmed from a single piece of data. One group even wrote an unclear solution: "*gradually moving down the graph, there are more insoluble elements / ions than at the top*". They seemed to lack the ability to organise all the data logically. Only one group described the rule more comprehensively as "*Na^+ and K^+ are both alkali metals, both have one outer electron and are very reactive.....and are soluble. Mg^{2+}, Ba^{2+} and Ca^{2+}*

are in column 2 and are very similar in their reactions with each compounds. Pb^{2+}, Zn^{2+}, Ag^{+} *and* Fe^{2+} *are all transition metals and their properties vary in each compound, their solubilities are vary*".

To predict the solubilities of strontium hydroxide and strontium sulphate, only one group reached an approximate answer. The other four groups did not succeed. Although they explained that the strontium is between calcium and barium in the Periodic Table and expected its solubility is to be between them, they still could not suggest a reasonable answer. In part 3 ("*mix a solution of magnesium chloride with a solution of potassium hydroxide, what might happen?*"), similarly, no one could produce a definite answer. Only one group mentioned "*the magnesium would not dissolve completely in the mixture as it is very insoluble in* OH^-; *the* K^+ *would be soluble in the mixture as it is soluble in both* OH^- *and* Cl^-".

7.6.2 Responses from Endpiece

This unit used the first and the third version of the Endpiece. The first version of the Endpiece included thirteen closed questions and eight open questions; the third version of the Endpiece included thirteen closed questions and two open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed responses to closed questions is shown in Table 7.11. As the numbers of pupils participated in the second stage of test is few (14), their responses to closed questions has not been summarised.

Table 7.11 Summary of Fixed Response Questions in Endpiece (Unit 13 First Data Collection)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	0	3	6	18	7
The problem was difficult.	18	8	2	5	1
I found that solving this problem was satisfying.	0	8	15	6	5
The problem was completely new to me.	9	8	6	8	3
I learned nothing from the problem.	4	6	10	14	0
I had enough previous knowledge to solve the problem.	2	6	11	12	3
I prefer solving problems on my own.	0	0	6	12	15
We worked well together as a group.	11	15	5	1	2
We did not share the work out evenly in our group.	2	5	6	14	7
I found the group discussion helpful.	8	18	5	2	1
At the end, we were not sure we had the correct answer.	5	12	7	8	2
I could not have solved the problem by myself.	10	8	8	6	2
I needed the other group members to help me remember background information	9	15	2	6	2

The problem seems to be difficult for most pupils (26 of 34). A majority of pupils also did not enjoy solving the problem (25 of 34). They tended to find the problem unsatisfying and they felt they lacked knowledge.

As the responses to eight open questions in the first version of the Endpiece, pupils expressed their opinions are listed:

For the following problems, there were no useful comments arising from them:

Question 1: *What did you do first to solve the problem?*
Question 2: *What was the second step?*
Question 4: *What was the easiest part in the problem?*
Question 7: *In what ways did working in a group help to solve the problem?*
Question 8: *What have you learned from the problem?*

Question 3: What did you need to know before you began?

Typical responses were:

(a) *about solubility of salts (8);*
(b) *Ions and bonding (3);*
(c) *the Periodic Table, the symbols for each element and molecular formula (5);*
(d) *identified elements in table*

Obviously, they needed to identify the symbols of elements and the solubility of each compound.

Question 5: What was a hindrance in preventing you from reaching a solution?

Typical responses were:

(a) *the table was quite complicated and to understand (5);*
(b) *it took a long time to find the pattern (4);*
(c) *not all the patterns went through all the solubility;*
(d) *the patterns were not complete (3);*
(e) *we did not know how to do it;*
(f) *confusing and not being sure;*
(g) *the question is hard and difficult;*
(h) *looking at all the different numbers;*
(i) *strontium was not on the table.*

They appeared to be confused by the given table which contains complicated data, and also felt did not have enough time to figure out the solubility pattern.

Question 6: How did you overcome obstacles in the problem?

Some pupils (5 of 34) replied that they did not overcome obstacles. Most pupils (11) have the same responses: "*discussed it, or shared all knowledge*". Others' comments were "*used the Periodic Table*", "*looked for elements in the same group on the table*" or "*helped from teacher*".

As the responses to **two open questions in the third version of the Endpiece**, pupils expressed their opinions as listed:

Question 1: What did you need to know before you began?

Typical responses were:

(a) *about solubility (4);*
(b) *we needed to know symbols and the names of the compound (3);*
(c) *about the elements' valencies (3);*
(d) *we needed to know what all the columns were; i.e. halogens, alkali metals, and if they were reactive or not (3).*

These groups of pupils searched further information on the Periodic Table, the elements' valencies and the properties of various columns of the Periodic Table were indicated as the important factors.

Question 2: What made it difficult for you to solve the problem?

Typical responses were:

(a) *we had never done a question like this before;*
(b) *lack of knowledge of chemistry (4);*
(c) *the numbers being so varied and information we never knew before;*
(d) *the patterns were not immediately apparent but working together made it easier to remember similar properties and the columns' numbers (3);*
(e) *the amount of information I had to take in which became irrelevant at the end.*

7.6.3 Information from Tape Recordings

Although most groups were recorded, little of significance emerged from the recordings. Almost all could handle the problem without too much difficulty.

7.6.4 Analysis Summary

There is clear evidence of confusion, despite the process of pattern seeking being relatively straightforward. This suggests that there are problems deriving from working memory space overload where the pupils simply could not take in so much information and discern any patterns. There is no evidence from the second data collection stage that the removal of one part made things any easier. It looks like the pupils were so swamped with data that they were unable to sort things out to grasp the key principles and then apply them.

7.7 *Unit 16*: Bonding

The unit was used at the first data collection stage with 20 groups (56 S3 pupils) taking part in solving it. The main task is to work out a way to find out what type of bonding exists in aluminium chloride ($AlCl_3$). The information of four types of chemical bonds (covalent, polar covalent, ionic and metallic) was provided. Pupils have to decide how to spend the £100 budget to select the useful experiments' results to solve the problem. During the process of problem solving, the researcher had to provide the results of various experiments to pupils. The information to be given is:

Melting point:	*does not melt, sublimes at 193 ° C.*
Boiling point:	*sublimes.*
Solubility in water:	*extremely soluble.*
Electrical conductivity as dissolved:	*solution conducts very well.*
Electrical conductivity as melt:	*does not melt.*
React with water:	*dissolves rapidly, sometimes with a sight "fizz".*

The unit worked quite well with pupils, the element of financial competitiveness being appreciated.

7.7.1 Pupils' Answers to The Unit

The bonding in pure aluminium chloride is polar covalent in all phases. But when it reacts with water, hydrated aluminium ions and chloride ions will be released. In this phase, the bonding is ionic. Among these 20 groups, only three groups found out aluminium chloride has polar covalent bonding. The experiments they chose to buy were (a) melting point, (d) electrical conductivity as dissolved or (f) reaction with water. Four groups concluded that the type of aluminium chloride was covalent and other five groups chose ionic bonds. The remaining groups did not finish the task and thus had no answer. The experiments they decided to purchase was very varied. Although they seriously engaged in solving the problem, it seems to be difficult for them to make clear out decisions.

7.7.2 Responses from Endpiece

This unit used the first version of the Endpiece which included thirteen closed questions and eight open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed responses to closed questions is shown in Table 7.12.

Table 7.12 Summary of Fixed Response Questions in Endpiece (Unit 16)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	6	26	16	6	2
The problem was difficult.	2	19	19	15	1
I found that solving this problem was satisfying.	10	18	20	5	3
The problem was completely new to me.	12	17	9	14	4
I learned nothing from the problem.	3	8	18	19	8
I had enough previous knowledge to solve the problem.	5	28	13	9	1
I prefer solving problems on my own.	4	5	8	23	16
We worked well together as a group.	20	24	9	2	0
We did not share the work out evenly in our group.	3	2	11	30	10
I found the group discussion helpful.	15	27	9	3	1
At the end, we were not sure we had the correct answer.	5	21	15	12	3
I could not have solved the problem by myself.	10	17	13	9	7
I needed the other group members to help me remember background information	9	19	16	10	2

The pattern of responses indicates that the problem was seen as difficult and new although they felt that they had enough knowledge to tackle it. They seemed to enjoy the experience and found it satisfying. Groups clearly went well. Observation certainly confirmed the very positive attitudes, perhaps caused by the slightly competitive nature of the problem where they had to spend a limited budget effectively.

As the responses to eight open questions in the first version of the Endpiece, pupils expressed their opinions are listed:

For the following problems, there were no useful comments arising from them:

Question 1: What did you do first to solve the problem?

Question 2: What was the second step?

Question 4: What was the easiest part in the problem?

Question 7 :In what ways did working in a group help to solve the problem?

Question 8: What have you learned from the problem?

Question 3: What did you need to know before you began?

Typical responses were:

(a) *knowledge of covalent, ionic and metallic elements / compounds (9);*
(b) *the difference between ionic and covalent compounds (4);*
(c) *if metallic or non-metallic (4);*
(d) *all type of bonding (13);*
(e) *the reactivity series (3);*
(f) *what we were looking for (4);*
(g) *the Periodic Table;*
(h) *$AlCl_3$ turns straight to a gas.*

Question 5: What was a hindrance in preventing you from reaching a solution?

Typical responses were:

(a) *the compound changed to a gas when melted (3);*
(b) *only have 100 pounds to spend (12);*
(c) *we did not know from previous knowledge (3);*
(d) *gaining the wording of the problem (3);*
(e) *ionic and covalent bond had similar properties / compounds(3);*
(f) *the solution is not melting (3);*
(g) *agreeing on what we should buy (3);*
(h) *the different results;*
(i) *chose wrong experiment.*

Question 6: How did you overcome obstacles in the problem?

Most pupils (23) have the same responses: "*discussed it, or helped each other*". Others' comments were "*by buying test results*" or "*tried other ways of testing*".

7.7.3 Analysis Summary

Although this problem went really well with pupils (there was a buzz of involvement and clear enjoyment), one clear impression left from all the evidence is pupil unease and uncertainty (almost intellectual insecurity) when faced with ambiguous data. This is not surprising in that so much teaching tends to leave pupils with a "right-wrong" view of knowledge. This unit challenged this and also raised the difficulty when an experiment could not give an unequivocal answer.

Chapter Eight

Other Types of Problems

Three types of problems are discussed in this chapter. For a type 2 problem such as *unit 7*, the data and the goal are given but the method is unfamiliar. Pupils have to look for parallels to known methods. For a type 3 problem such as the *unit 2*, the data are incomplete, the method is familiar and the goal is open. Pupils have to analyse the problem to decide what further data are required in order to solve problem successfully. For a type 5 problem such as *units 12* and *18*, the data are given, the method is familiar but the goal is open. Pupils have to make a decision about goals. These units are listed:

Unit 2: *Which is the Best Fuel?*
Unit 7: *Iron: How can we obtain it? (not used in this project)*
Unit 12: *Salt, Salts, and pH*
Unit 18: *Rates of Reaction*

8.1 *Unit 2*: Which is the Best Fuel?

This unit was used twice, once in Scotland, once in Taiwan. At the second data collection stage, 12 groups consisting of 35 (S5) Scottish pupils which drawn from two schools took part in solving it. These pupils had been taught the concepts of combustion and how to balance equation in their normal teaching. A Word Association Test was conducted before they attempted the unit to check their understanding of the concept of combustion. Their discussions were tape recorded. At the third data collection stage, 22 groups consisting of 63 Taiwanese pupils participated in solving it. They did not complete a Word Association Test and their discussions were not tape recorded due to these pupils being organised in a large room where it was difficult to conduct tape recording.

The unit was in four parts. The main task of this unit was "*Suppose you were given 1 kg (1000g) of each fuel, which fuel would give you most energy?*" In part 1 and part 2, pupils were asked to balance the combustion equations of these three different fuels (coal, oil and gas) and calculate the formula masses of each fuel. In part 3, an assumption that "*the energy released is related to the number of molecules formed*" was given. Pupils had to employ the assumption to determine which fuel would provide the most energy. Afterwards, they had to consider if the assumption is reasonable.

8.1.1 Word Association Test Results

The main concept in this unit is *Combustion.* Pupils were given a series of related words and were asked to note as many related ideas as possible in a fixed time. The concept map is presented in Figure 8.1.

The evidence from the Word Association Test indicates that pupils have a sound understanding of the concepts of combustion. This is consistent with the fact that most pupils were able to complete the combustion equation. However, the results from the Word Association Test do not throw any light on the observation that most pupils were unable to solve part 3.

Unit 2 Which is the Best Fuel

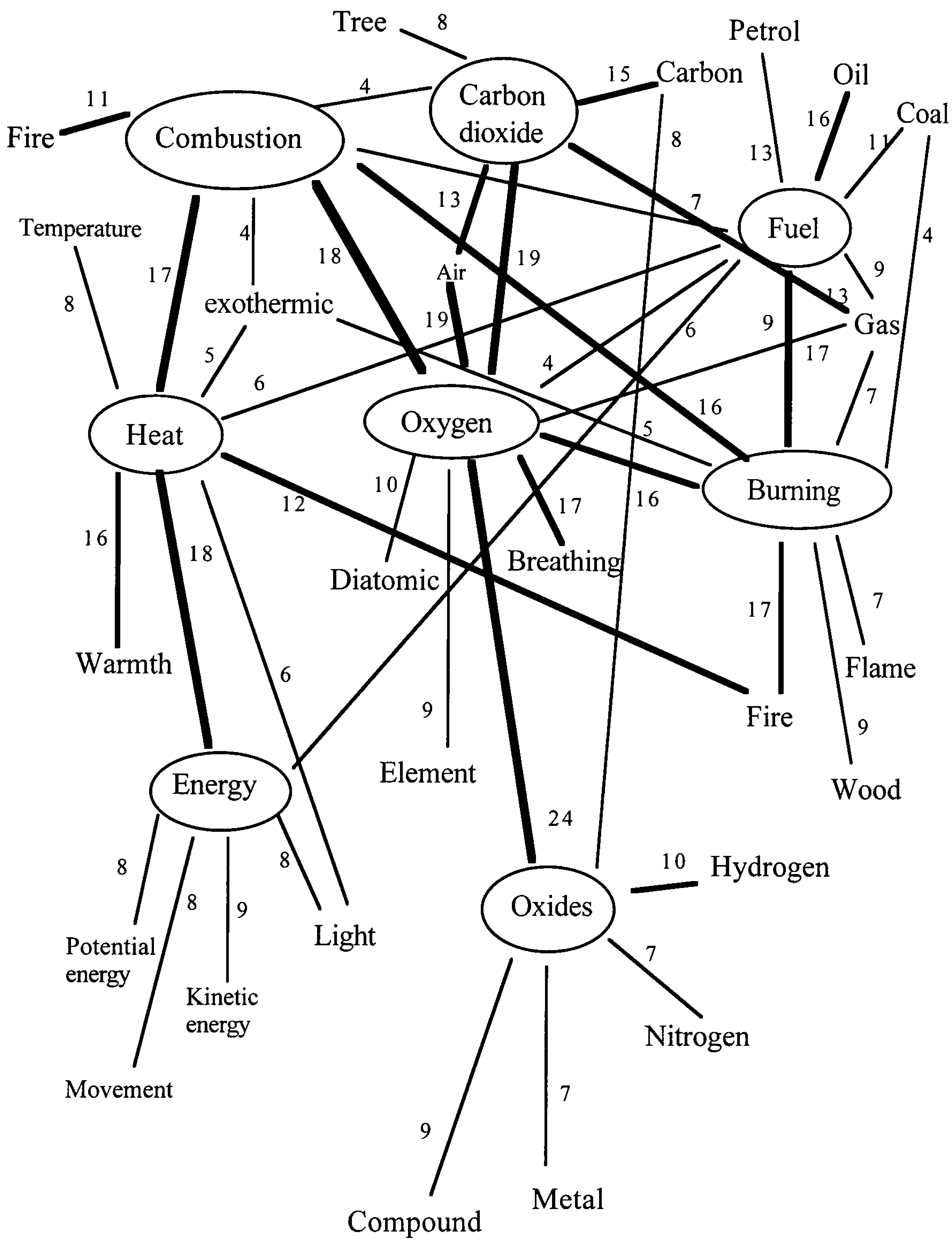


Figure 8.1 Concept Map II (Unit 2)

8.1.2 Pupils' Answers to The Unit

It is not difficult for pupils to write the combustion equations of fuels and calculate their formula masses, because the Scottish S5 pupils and the Taiwanese pupils have been taught this topic and regularly practised it. The combustion equations are:

$$C + O_2 \longrightarrow CO_2$$
$$C_{11}H_{24} + 17\,O_2 \longrightarrow 11\,CO_2 + 12\,H_2O$$
$$CH_4 + 2O_2 \longrightarrow CO_2 + 2\,H_2O$$

According to the given assumption, the relative number of molecules formed in each equation can be estimated by dividing 1000 g each fuel by its formula mass. It shows the gas (methane) gives the greatest number of product molecules and is likely to provide the most energy for each 1000g fuel burned. The relationship between the equation coefficients and the number of molecules formed is an important factor. If pupils did not notice it then they would not be able to reach a correct answer.

If the various bonds are similar in energy, then the energy released is approximately proportional to the number of molecules formed. In fact, the assumption is good enough to show that methane will release most energy.

8.1.3 Scottish Pupils' Answers

Not surprisingly, most groups (9 of 12) of pupils were able to write the combustion equations. Two groups made a mistake about the products of CO_2 and H_2O from oil and gas: one group wrote "$C + H_2O$" and another group wrote "$CO_2 + H_2$". They seem to forget that completely burning hydrocarbon will produce CO_2 and H_2O. Only one group was totally confused about the combustion. The equations they wrote were:

$$O_2 + C \longrightarrow C$$
$$O_2 + 11\,C + 24\,H \longrightarrow C_{11}H_{24}$$
$$O_2 + C + 4\,H \longrightarrow CH_4$$

Obviously, they did not understand the combustion reaction and lacked chemistry knowledge. Therefore, they also failed to calculate the formula masses of each fuel while the other 11 groups all obtained correct answers.

In part 3, most of pupils were unable to reach a correct solution except one group which had been given a hint were successful in solving this part. By looking at their tape transcript, the given hint is obvious, as the following tape transcript reveals:

T (teacher):	*So you think which one?*
A (pupil) :	*Coal.*
T:	*Why do you think it is coal?*
A:	*Because it gives the more molecules formed.*
T:	*Why don't you think the part 1?..........you see the energy released is related to the number of molecules formed, so there are two factors. One is the grams, another is the equation, you have to put them together................* *Do you get it?*
A:	*No,..........*
T:	*All right, you see, one carbon gets one CO_2. One oil gets 12 CO_2 and 11 H_2O, the total molecules is 23. Here is just one oil, but from your data, the oil is 7.*
A:	*Well, that would be multiple with 23?*
T;	*You quite reach that.......*
A:	*One molecule there, 23 there, and 3 there. So we just multiple by.......(they finally got the numbers of molecules formed: 83, 161 and 187.5)*

One group thought that "*the oil gives out the most energy because there are more molecules formed in the balanced equation*". They simply seemed to use the equation to deduce their answer and did not know they have to consider the factor of the 1000 g weight of fuel. The other groups understood that they have to divide the 1000 g of each fuel by its formula mass but directly concluded that "*coal would give most energy*". However, they were unable to link the part 1 and part 2 information to the part 3 and this led them to be unsuccessful in solving this problem.

To justify whether the assumption is fair, the key knowledge is the overall energy changes depend on bonds broken in reactants and bonds made in products. It was expected that through discussion pupils might be able to share ideas which would lead towards these ideas. In fact, only two group were able to reach this answer. Their conclusions were "*this is not a fair assumption because such factors on the bonding, structure and intermolecular forces have to be taken into account* " and "*bonds need energy to be broken and formed*". Four groups pointed out the assumption is not fair but had some unclear reasons such as "*the molecular size could vary giving different amounts of energy*", "*one of the fuels is only one element and the other two contain hydrogen*" or "*because each substance has its own strength, no matter how many molecules the weaker substance has, the stronger would still release a lot energy more than the weaker*". The other groups could not make a reasonable justification although some of them had the seemingly accurate idea about "*bonding*". For instance, one group wrote "Yes, *the smaller the molecules the more energy is released; because the less bond to break*"; another group expressed "*it is a fair assumption because with more molecules there is more energy available to react with*".

8.1.4 Taiwanese Pupils' Answers

In a similar way, all Taiwanese pupils obtained the correct combustion equation of each fuel and their formula masses. Only two groups made a slight mistake in the calculation of formula masses.

In part 3, almost half of groups (10 of 22) were able to obtain the correct answer. They first converted the 1000 g weight of each fuel into moles, then multiplied the moles by the sum of the coefficients of products to gain the overall numbers of products formed. Eventually, they understood that gas is the best fuel which would give out the most energy. A typical calculations is shown as below:

> *Coal is 1000/12 =83.33 moles, it produces 83.33 mole of CO_2*
> *Oil is 1000/156 = 6.4 moles, it produces (6.4 x 11) CO_2 and (6.4 x 12)H_2O.*
> *The total is 147.2 moles.*
> *Gas is 1000/16 =62.5 mole, it produces (62.5 x 11) CO_2 and (62.5 x 12) H_2O.*
> *The total is 187.5 moles.*
> *Therefore, gas would give out the most energy.*

The other 12 groups failed in solving this part problem. There is an interesting finding that some groups selected oil as the best fuel that because it "*contains the most amount of carbon atoms*". They explained that "*burning one more carbon or methyl, the fuel will give out an extra 13 kcal / mole energy*". One group even stated that "*oil has 11 carbons, it will release 143 kcal; coal only has one carbon, it will release 13 kcal; CH_4 has one carbon, it will also release 13 kcal.*" Obviously, they seemed simply to recall the prior knowledge about the combustion energy and linked it to the number of carbons, then directly jumped into the answer without deliberation. Another group considered the % of C in each fuel and selected coal as the best fuel, their reason was: "*coal contains 100% C, oil contains 132 / 176 = 75% of C, gas contains 12 /16 = 75% of C. Because burning carbon atom will give out more energy than burning hydrogen atom, so coal release the most energy*". They did not understand at all how to put the information together to solve the problem.

In addition to the above errors, the Taiwanese pupils also made other mistakes. One group did the mole calculation accurately but made a wrong linkage although they finally obtained a correct answer. They linked the combustion equation with the used moles of oxygen and pointed out that "*coal needed 83.3 moles of oxygen, oil needed 1.069 moles of oxygen and gas needed 125 moles of oxygen; therefore it is gas which would give out the most energy*". By checking the calculations in their notes, oil should need 6.41 x 17 = 108.9 moles of oxygen. Apparently, they made a calculation mistake and also drew a wrong conclusion: "*the more used moles of oxygen, the more energy released*". In a similar way to the Scottish pupils, three groups only considered the moles of products which were converted from the 1000 g weight but were unable to combine it with the combustion equation. They thought that "*the less formula mass of molecule the more moles it has*; *when the mole increased the energy released also increased*". That is the reason why they chose coal as the best fuel.

Simply by recall, one group referred to the oil is the best fuel for a century because many previous experiments have proved it. They obviously did not understand what the meaning of the part 3 problem was. Other two groups also confused at this part. Looking at their answers, one group said: "*oil has the biggest formula mass than coal and gas, so oil would provide the most energy*"; another group expressed that "*based on $n = W/M$, the numbers of moles is equal to the weight, so their formula masses are the same, they all released the same amount of energy*". Evidently, they seem had a misleading knowledge about the concept of mole and formula mass.

In part 4, to justify whether the assumption is fair, 11 groups agreed that the assumption is fair. Their explanations were vary and listed as the follows:

(a) *because the carbon atoms increased, the more energy released.*
(b) *the more molecules formed, the collision of molecules increased and this lead to release more energy.*
(c) *because the energy released is related to the Enthalpy Change (ΔH). It will be an exothermic reaction when the Heat of Formation is bigger than the Heat of Reaction . In addition to the number of molecules, the types of molecules also have to be considered.*
(d) *when a fuel is burning, the bigger formula mass the fuel has the more energy it releases.*
(e) *if oil releases the most energy, it also produces the most moles of CO_2 and H_2O.*
(f) *it is based on the Hess's Law.*
(g) *when the energy released it would cause the energy level (En) decreased and formed new molecules.*

Because these pupils have been taught some thermochemistry, they were able to use some of the terms in an attempt to explain what was happening. However, these pupils did not clearly link this knowledge to the main issue of the assumption although not one of them ever mentioned that the types of molecules have to be considered.

The other 11 groups disagreed with the assumption for various reasons. Only two groups were able to draw the reasonable conclusions. The first group had a wide view: "*the energy released is related to the structure of the fuels, their formula masses and the balanced equations*"; the second group also noticed that "*when different compounds are formed, the demanded energy are various; moreover, the amount of products may also be different* ". With respect to the other groups' explanations, two groups had a misconception about the moles; they disagreed because "*the energy released is not* *related to the number of molecules formed but related to the mole of molecules formed*". In addition, if pupils did not associate the concept of mole with the combustion equation logically, they also could not make a plausible conclusion. For instance, one group noticed that oil produces 11 CO_2 and 12 H_2O, and thought it must be oil which would release the most energy if the energy released is related to the number of molecules formed. On the other hand, they also found out that coal would give out the most energy because it has the largest moles (83.3 mole). Obviously, they were unable to link these two parts of information together.

Interestingly, there were two reasons appeared which seem to be irrelevant to the problem. One group highlighted the influence of C=C bond on the released energy. Their idea was: "*because the pi bond in C=C bond is more stable than the sigma bond in C-H bond, the molecules which contain C=C bond would release more energy than those molecules which contain C-H bond* ". In fact, these three fuels did not have C=C bond and the comments reveal some confusion in understanding. Another group made the conclusion that "*the energy released and the new molecules formed are related to the three states of substance: solid, liquid and gas. Coal is made up of pure carbon, so it contains the most carbon and does not have the three states' problem, therefore coal would release the most energy, not gas*". To solve the problem, the key point is the various bonds and the structure of compounds not the three states of substance. Regrettably, pupils seemed to remember fragments of knowledge but did not understand its real meaning at all. It can be seen from one group's statement: "*in many chemistry research reports, they addressed that the energy released should based on the experimental result. If we use the assumption to calculate the energy, the outcome will be less accurate*".

8.1.5 Responses from the Endpiece

This unit used the second and the third versions of the Endpiece. The second version of the Endpiece included thirteen closed questions and six open questions; the third version of the Endpiece included thirteen closed questions and two open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed responses to closed questions is shown overleaf in Table 8.1and Table 8.2.

Table 8.1 Summary of Fixed Response Questions in Endpiece (Unit 2 The Scottish Pupils)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	6	17	12	0	0
The problem was difficult.	9	18	5	3	0
I found that solving this problem was satisfying.	2	25	7	0	0
The problem was completely new to me.	16	7	5	5	1
I learned nothing from the problem.	1	2	7	16	8
I had enough previous knowledge to solve the problem.	2	15	8	8	2
I prefer solving problems on my own.	1	9	10	10	5
We worked well together as a group.	11	17	4	2	0
We did not share the work out evenly in our group.	1	7	8	12	7
I found the group discussion helpful.	7	19	8	1	0
At the end, we were not sure we had the correct answer.	10	9	7	8	1
I could not have solved the problem by myself.	7	10	7	10	0
I needed the other group members to help me remember background information	8	11	7	6	3

Table 8.2 Summary of Fixed Response Questions in Endpiece (Unit 2 The Taiwanese Pupils)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	4	36	14	8	1
The problem was difficult.	2	14	32	14	1
I found that solving this problem was satisfying.	0	33	21	6	1
The problem was completely new to me.	8	27	11	14	3
I learned nothing from the problem.	1	2	13	41	6
I had enough previous knowledge to solve the problem.	1	14	32	14	1
I prefer solving problems on my own.	4	17	19	21	2
We worked well together as a group.	8	34	13	8	0
We did not share the work out evenly in our group.	0	6	19	29	9
I found the group discussion helpful.	10	38	12	1	2
At the end, we were not sure we had the correct answer.	5	22	25	9	2
I could not have solved the problem by myself.	5	20	20	13	5
I needed the other group members to help me remember background information	7	43	8	2	3

Looking at these two tables, it is obvious that most of the Scottish and the Taiwanese pupils both have a positive pattern in "*enjoyable*", "*satisfying*" and "*the problem was new*". Referring to the difficulty of the problem and whether they have enough knowledge, most Taiwanese pupils (32 of 63) have a neutral answer while the Scottish pupils seem to see the problem as more difficult, perhaps reflecting the fact that their syllabus had not yet covered any topics relating to thermochemistry.

As the responses to six open questions in the second version of the Endpiece, pupils expressed their opinions are listed:

(Two Scottish schools participated in solving this unit and filled in the second and the third version of the Endpiece, their responses were added together. The Taiwanese pupils only filled in the third version.)

Question 1: After reading the problem, what did your group discuss first?

Typical responses were:

- (a) *whether water is formed in the combustion of coal (3);*
- (b) *talk about how we would tackle it (4);*
- (c) *what about the substances were (3);*
- (d) *we discussed about which fuel is the best (4);*
- (e) *how to figure out how many molecules were used in a balanced equation (3);*
- (f) *we discussed how to balance the equations (3).*

By observation, the S5 pupils were more confident in group discussion and this led them to be able to go straight towards the key point.

Question 2: What was the second step your group took to solve the problem?

Typical responses were:

- (a) *we balanced the chemical equations and found their formula masses (9);*
- (b) *calculate how much of each fuel we have (3);*
- (c) *how many molecules 1000 g produced.*

Practically, the approaches they took focussed on part 2 of the problem.

Question 3: What did you need to know before you began?

Typical responses by the Scottish pupils were:

- (a) *we needed to know how to balance equations and how to calculate formula masses (21);*
- (b) *basic maths and chemistry knowledge (3);*
- (c) *we needed to know different types of formula (3);*
- (d) *we needed to know what combustion was and what was the products of burning fuels (6);*
- (e) *how to work out how many molecules / moles were formed from each fuel (3).*
- (f) *how compounds join to form others.*

Significantly, how to write a balanced equation and work out the formula masses is the main comments from pupils.

Typical responses by the Taiwanese pupils were:

- (a) *have strong knowledge about "Thermochemistry" (36);*
- (b) *basic chemical calculations such as calculate formula mass and mole (38);*
- (c) *how to write the balanced combustion equations (42);*
- (d) *we needed to know what the influence of chemical equation by moles was;*
- (e) *how to work out the Energy of Reaction and the variety of energy ` released;*

(f) *about mole and how to apply it (10);*
(g) *we needed the basic concept of thermochemistry to work out the demanded energy;*
(h) *we needed to know the atoms are reserved;*
(i) *burning organic compound will produce CO_2 and H_2O;*
(j) *we needed to know the coefficient of chemical equation is equal to the mole ratio of each compound;*
(k) *general chemistry knowledge (13);*
(l) *the organic chemistry knowledge;*
(m) *the energy level (En).*

These responses indicated a much wider range of knowledge which was seen as relevant. This might reflect the greater coverage of chemistry by these pupils at this stage.

Question 4: What made it difficult for you to solve the problem?

Typical responses by the Scottish pupils were:

(a) *when we had different answers, our group had difficulty in agreeing in the solution (4);*
(b) *it was difficult because of the calculations (8);*
(c) *we were not sure of the product of reactions;*
(d) *we did not know whether we were on the right tracks or not (3);*
(e) *we were not sure that our equations or formula masses were correct;*
(f) *had not done anything like the equation given before;*
(g) *not knowing how to relate the first two parts;*
(h) *I did not understand some questions until explained;*
(i) *the large numbers we had to work with and the way multiple formula were required to find the correct answer.*

The calculations seems to be the main difficulty for pupils. In addition, the conflicts of different opinions between group members and the uncertainty that whether their thinking was correct also blocked them.

Typical responses by the Taiwanese pupils were:

(a) *we had difficulty in discussion and agreeing in the same solution (6);*
(b) *thermochemistry (2);*
(c) *part 3, because we needed to know what the products was and had to calculate the released energy (19);*
(d) *part 3, first we used $E=mc^2$ but then thought the combustion equation is related to the "thermochemistry"*
(e) *part 4, because we had to write our opinions / needed the profound concepts and thinking carefully / did not know how to answer it / did not have clear ideas / we had never done this kind of problem before so we needed more time (16);*
(f) *it is difficult for us to decide which fuel was the best (3);*
(g) *part 3 and part 4, because we did not have clear ideas / the problem was abstract / we knew what the answer was but could not provide a reasonable explanation / the problem was unusual, we had to think it very long (7);*
(h) *we had never paced a problem like it before, so we did not know where to start;*
(i) *to construct our ideas.*

Question 5: How did you overcome obstacles in the problem?

Typical responses were:

(a) *we went through all the methods to find the most likely answer (3);*
(b) *we remembered from the past work, form which we had done (3);*
(c) *we discussed our opinions and came to a calculation for the problem (10);*
(d) *did long sums, long multiplication and long division (3).*

They overcame the obstacles by retrieving the knowledge from their long term memory or group discussions.

Question 6: What do you think you learned from trying to solve it?

Most pupils found out the advantages of working in groups such as "*it is easier to tackle the problems*", "*I learned to compromise and discuss things in group*" or "*taking other people opinions into account can logically solve a problem*". A few of them pointed that they"*improved their maths*". Only one pupil mentioned that he learned that "*molecules are not related to the energy released*".

8.1.6 Information from Tape Recordings

Although most groups were recorded, little of significance emerged from the recordings. Almost all could handle the problem without too much difficulty.

8.1.7 Analysis Summary

For all pupils, this unit was new and this was reflected in their comments. Overall, pupils managed to use balanced equations and worked out formula masses. Many could make a good attempt in relating the 1000g to the formula masses. However, few pupils were able to bring these two ideas together to obtain a correct answer. These observations are consistent with the suggestion that the creation of a pathway between "islands" of knowledge or skills is extremely difficult. This may be one of the critical aspects in seeking to solve open-ended problems successfully. It raises the question: can the skill of linking ideas be developed, does it develop naturally with age, or do the links have to suggested by the teacher ?

8.2 *Unit 12*: Salt, Salts and pH

The unit was used at the first data collection stage with 20 groups (58 S3 pupils) taking part in solving it. The main task of this unit is to draw many conclusions from a table

(Table 8.3) which provided various salts and the pH of their solution in water. Because the goal is open, an example (*salts containing potassium always seem to have a pH of 7 or more*) is given as a hint to help pupils drawing conclusion.

Table 8.3 The Salts and the pH of Their Solution

Salt	pH
Iron (II) sulphate	1
Aluminium chloride	3
Zinc (II) sulphate	3
Copper (II) nitrate	3
Sodium chloride	7
Potassium sulphate	7
Calcium chloride	7
Sodium nitrate	7
Sodium carbonate	10
Potassium carbonate	11

8.2.1 Pupils' Answers to The Unit

It would be more successful to solve the problem if pupils begin doing it from comparing the similarity between the salts with their pH. In fact, most pupils were able to draw simple conclusions such as "*all salts containing iron have a pH of 1*" or "*all salts containing aluminium, zinc and copper have a pH of 3*". On the other hand, some groups merely copied the given example to wrote their conclusion. For instance, "*salt contains chlorides have a pH of 3 or more*" or "*salts containing sodium have a pH more than 7*" was found in many groups. Only a few of groups understood to draw their conclusions based on the Periodic Table, like "*all the alkali metals in the table produce a neutral or alkali solution but transition metals produce acidic solutions*", or "*all group 1 metals will make an alkali solution*". However, all the pupils almost were able to reach some correct conclusions of varying degrees of generalisability.

Astonishingly, some unexpected conclusions emerged which, in some cases, are partly correct. Four groups mentioned that "*the salts containing the sign of (II) are acidic*". They seemed not to be able to use the term of "*valency*". Others conclusions were: "*the acidic salts have no alkali metals in them*", "*anything with carbon in it is an alkali*" or "*double bonding metals seem to have a low pH*" etc.

8.2.2 Responses from the Endpiece

This unit used the first version of the Endpiece which included thirteen closed questions and eight open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed responses to closed questions is shown in Table 8.4

Table 8.4 Summary of Fixed Response Questions in Endpiece (Unit 12)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	1	14	35	2	6
The problem was difficult.	0	15	18	21	4
I found that solving this problem was satisfying.	1	15	23	13	5
The problem was completely new to me.	15	20	6	10	5
I learned nothing from the problem.	5	2	16	34	1
I had enough previous knowledge to solve the problem.	4	17	14	14	9
I prefer solving problems on my own.	2	4	6	18	27
We worked well together as a group.	30	21	3	1	2
We did not share the work out evenly in our group.	2	8	5	24	18
I found the group discussion helpful.	8	38	9	1	1
At the end, we were not sure we had the correct answer.	10	14	21	13	0
I could not have solved the problem by myself.	11	8	12	20	6
I needed the other group members to help me remember background information	0	19	18	12	8

Although the problem was developed from examination paper questions, most pupils (35 of 58) still felt the problem was new to them. Referring to enjoyment, most of them (35 of 58) have no strong agreement in it while views about difficulty were indicated neutral views.

As the responses to eight open questions in the first version of the Endpiece, pupils expressed their opinions are listed:

For the following problems, there were no useful comments arising from them:

Question 1: *What did you do first to solve the problem?*
Question 2: *What was the second step?*
Question 4: *What was the easiest part in the problem?*
Question 7: *In what ways did working in a group help to solve the problem?*
Question 8: *What have you learned from the problem?*

Question 3: What did you need to know before you began?

Typical responses were:

(a) *what pH is (17);*
(b) *the pH table and the Periodic Table (5);*
(c) *what "ate" on the end of an element means (3);*
(d) *about naming compounds;*
(e) *what were alkalies and acids (6)*
(f) *I needed to know about acidic and alkali metals (5);*
(g) *which substances were metals and which were not;*

(i) *what elements the salts contained (5);*
(j) *a knowledge of what to do and how to get answers from information (3).*

Undoubtedly, it appears that most pupils regarded the pH as an essential knowledge. The basic information about alkali and acid also play an important role.

Question 5: What was a hindrance in preventing you from reaching a solution?

Typical responses were:
(a) *we did not understand the question at first (6);*
(b) *some elements only appeared once (3);*
(c) *lack of enough information (4);*
(d) *could not find reasonable similarities (3);*
(e) *lack sufficient time to discuss conclusions (5);*
(f) *working out all the different parts of the salt solutions (3);*
(g) *too many different results we could have had longer.*

It is astonishing that pupils thought the failure of finding reasonable similarities was a hindrance even though an example has been given to them as a hint.

Question 6: How did you overcome obstacles in the problem?

Similar as other units, the typical responses were "*discussed the problems in group and wrote down the notes*", "*asked the teacher*" and "*we read the question over and over*".

8.2.3 Analysis Summary

Pupils tended not to look for patterns based on the Periodic Table but treated the metals separately. This may be a feature specific to this unit and may reflect on the way the Periodic Table is being used (or not being used) as a unifying theme in chemistry

However, the observation is consistent with the suggestion that the ability to generalise is not one which comes easily. As a feature of solving problems successfully, it is possible that it needs development or, indeed, encouragement from the teacher. It is possible that the skill of generalisation is a specific example of the skill of being able to link related concepts together. It has been noted that this does not happen easily.

8.3 *Unit 18*: Rates of Reaction

The unit was used at the first data collection stage with 9 groups (25 S3 pupils, at the start of their course) taking part in solving it. The reaction of zinc with dilute hydrochloride acid and its four experiments' results were provided which the reaction time and the volume of hydrogen were tabulated. Firstly, pupils were asked to plot graphs (graph paper was provided), sharing this out to save time. After completing the graphs, they have to work out the factors that influence the speed of the reaction by comparing a pair of experimental graphs. The full unit is shown in Appendix A.

8.3.1 Pupils' Answers to The Unit

These early S3 pupils have studied little chemistry course at this stage when they were asked to solve the problem. It is not surprisingly that they needed hints and general encouragement. By observation, it revealed that they did not know the technical term of "1 M" (standing for "1 Molar" and meaning the concentration of solution) although the explanation about 1M (1 mole per litre) has been given in the problem. In addition, some groups did not even know how to start to plot the graphs. As a result, although they finally completed the graph, many still were unable to find out that the catalyst and the size of reactant would influence the rate of reaction. However, overall, most groups managed to make sensible deductions from the discussion of the graphs they had drawn.

In part (1) all the pupils obtained correct answers like, "*there is less zinc used in the experiment 2, so there was not a lot of hydrogen produced*". In part (2), most groups (6 of 9) were able to spot that the increased temperature resulted in the hydrogen being released quicker in experiment 3 but no group mentioned the catalyst; only one group linked it to the concentration of dilute hydrochloric acid. Their answer was "*there was a larger amount of dilute hydrochloride acid in experiment 3*". In part (3), seven groups were able to spot that "*there is less hydrochloric acid or there is a lower temperature in experiment 4 than in experiment 1*". Only one group still stuck on the amount of zinc, they stated that "*there is more zinc in experiment 1 than in experiment 4*". In fact, one of the factors to affect the experiment 4 is the size of zinc (the zinc was in a larger lumps, not powdered) not the amount of zinc.

8.3.2 Responses from the Endpiece

This unit used the first version of the Endpiece which included thirteen closed questions and eight open questions. The pupils' responses to these two types of questions are summarised below. Firstly, the summary of fixed responses to closed questions is shown in Table 8.5 .

Table 8.5 Summary of Fixed Response Questions in Endpiece (Unit 18)

	Strongly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Strongly disagree*
The problem was enjoyable.	1	14	35	2	6
The problem was difficult.	0	15	18	21	4
I found that solving this problem was satisfying.	1	15	23	13	5
The problem was completely new to me.	15	20	6	10	5
I learned nothing from the problem.	5	2	16	34	1
I had enough previous knowledge to solve the problem.	4	17	14	14	9
I prefer solving problems on my own.	2	4	6	18	27
We worked well together as a group.	30	21	3	1	2
We did not share the work out evenly in our group.	2	8	5	24	18
I found the group discussion helpful.	8	38	9	1	1
At the end, we were not sure we had the correct answer.	10	14	21	13	0
I could not have solved the problem by myself.	11	8	12	20	6
I needed the other group members to help me remember background information	0	19	18	12	8

Most pupils (17 of 25) seem to enjoy solving the problem although they felt the problem was new to them (20 of 25).

As the responses to **eight open questions in the first version of the Endpiece**, pupils expressed their opinions are listed:

For the following problems, there were no useful comments arising from them:

Question 1: *What did you do first to solve the problem?*
Question 2: *What was the second step?*
Question 4: *What was the easiest part in the problem?*
Question 7: *In what ways did working in a group help to solve the problem?*
Question 8: *What have you learned from the problem?*

Question 3: What did you need to know before you began?

Typical responses were:
- *(a)* *how many chemicals were used in the experiment (8);*
- *(b)* *I needed to know the facts of the experiment (3);*
- *(c)* *how to make a graph and read the questions (5).*

They put much attention on the chemicals used in the experiment but they seemed unaware of anything about the chemical reaction.

Question 5: What was a hindrance in preventing you from reaching a solution?

Typical responses were:
- *(a)* *we did not read all the information properly;*
- *(b)* *we all disagreed the answers (3);*
- *(c)* *trying to find out what the difference was;*
- *(d)* *we were not sure if it was the amount of zinc or temperature that making the difference;*

(e) *we could not figure out what is was;*
(f) *thinking of the wrong answer;*
(g) *understanding the graphs (3).*

Question 6: How did you overcome obstacles in the problem?

Most pupils replied that they *"asked for help from the teachers"*. Others overcame obstacles by discussion.

8.3.3 Analysis Summary

Although pupils found some difficulties with unfamiliar terminology, they coped reasonably well with this problem. They managed to draw some conclusions but seemed to have an incomplete grasp of what was involved. Observation suggested that they found the concept of a chemical reaction an unfamiliar one: the idea that there were factors influencing rate seemed to be strange. This probably reflects the fact that almost no chemistry is studied by pupils before the beginning of S3 when they met the hint.

Chapter Nine

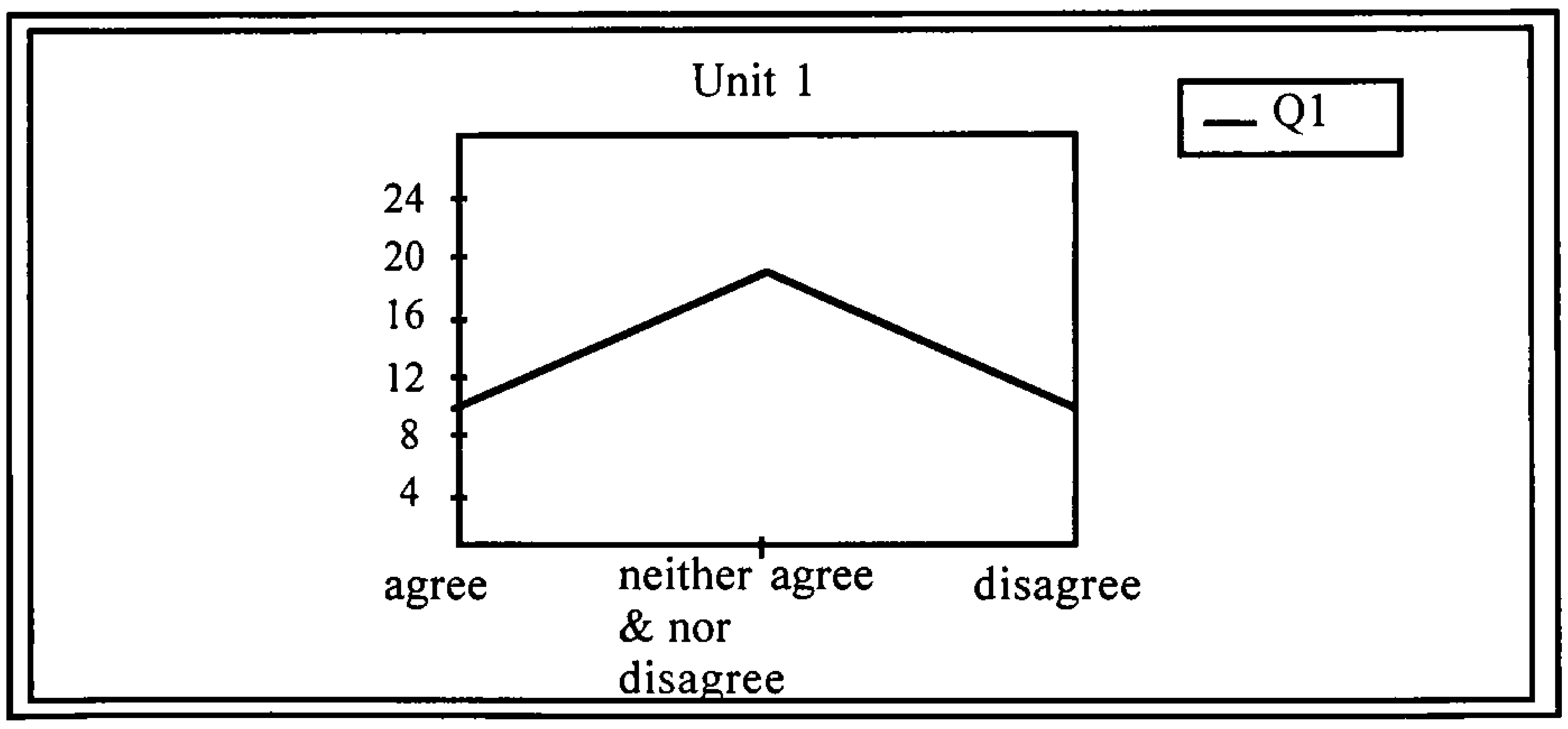
Statistical Results and Interpretation

In this chapter, an attempt will be made to bring together data from all the units used to establish patterns and draw conclusions.

The Endpiece in each unit included thirteen fixed questions. The results gathered from those fixed questions will be divided into two sections. Firstly, the overall pattern of responses from each question among the fourteen used units will be compared and summarised. Secondly, correlations between the thirteen questions of each unit will be presented and discussed. Finally, other evidence derived from observation and recorded tapes will be combined with the statistical results and interpreted further.

9.1 A Comparison of the Thirteen Fixed Questions

This section compares the responses of each question. In order to summarise the patterns of results, the responses for each unit are summarised graphically. A typical graph from question 1 in Unit 1 is given. The unit's title (unit 1) and the item of question (question 1) are placed on the top, the scale of responses is placed on the x-axis and the number of pupils is placed in y-axis (Figure 9.1). In the Endpiece, although the responses were placed in five categories, ranging from 'strongly agree' to 'strongly disagree', it is decided to group the pupils' responses into three categories because of sample sizes: (a) "*agree*" which summed by strongly agree and agree; (b) "*disagree*" which summed by strongly disagree and disagree; (c) "*neither agree nor disagree*". The full detailed thirteen questions' graphs for the fourteen units are given in Appendix G.



("agree" - 9, "neither agree nor disagree" - 18, "disagree" - 9.)

Figure 9.1. A Typical Graph from Responses to Question 1 in Unit 1

For some questions, all (or nearly all) the units produced graphs of similar shape while, for others, a variety of shapes was obtained. The first group are discussed under the title "common trends" while the latter group are referred to as "specific trends".

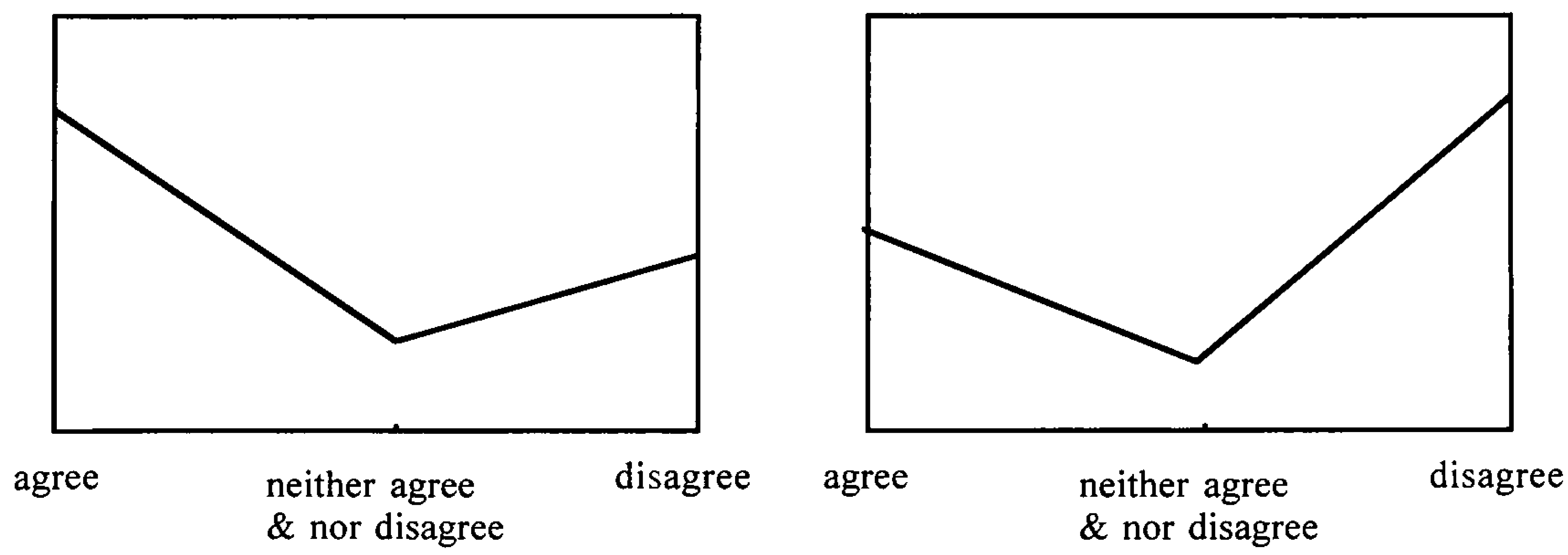
9.1.1 The Common Trend of Responses

The following six questions have a common trend of responses. These various trends and the rough shape of their graphs are presented as below.

(I) ***Question 4: The problem was completely new to me***
Pattern 1: almost all units were regarded as completely new except unit 5 (first version).

Discussion: In unit 5, the number of pupils who chose "disagree" is larger than other two scales. It is surprising that unit 5 was not regarded as new by pupils. As mentioned earlier, unit 5 has two versions. In the first version, it contained four questions about NO_2 which are related to the car engine in part 1. It is likely that the opposite pattern might have been caused by the pupils (S3) being familiar with the ideas behind these four questions. Nevertheless, these pupils could not propose reasonable explanations for part 2 problem (only one group reached the correct solution). On the contrary, by removing the four familiar questions and adding another simplified question in the second version, most of pupils succeeded in proposing a reasonable explanation but now regarded the problem as new. The difference in responses between these two versions of unit 5 is significant and was shown in page 89.

The common rough graph and the graph of unit 5 are shown as below (Figure 9.2):



(a) The common graph **(b) The graph of Unit 5**

Figure 9.2 Question 4: The Common Graph and the Specific Graph of Unit 5

(II) *Question 5: I learned nothing from the problem*
Pattern 2: pupils felt they had learned something.

Discussion: At the first and second versions of the Endpiece, pupils have been asked to write the outcome which they thought they have gained from solving a problem. In the third version, this open question was deleted because the outcome they indicated seem to be unrelated to the main purpose of this project. However, they still have some useful information that is consistent with the pattern 2. The thing pupils thought they have learnt generally focuses on three aspects. Firstly, they gave a rather positive attitude to group work. The opinions they frequently expressed are: "*group work is better than working alone*"; "*it is easier to tackle the problems in groups*"; "*it is helpful working in a group so that each of the members can help out*". The second one is about the specific chemical knowledge. For example, for unit 9, their opinion is "*we learnt how to work out volumes from balancing equations*". For unit 6, their opinion is "*we learnt how a heat pack really works*" or "*chemistry is around us all the time*". The third is about the idea of solving problems. They revealed some opinions such as:

(a) *I learnt to work my mind more extensively rather than coming up with a simple idea*;

(b) *remembering previous chemistry knowledge is important for solving harder questions*;

(c) I learned to compromise and discuss things in group;

(d) we have to take into account other possibilities than the ones which are in front of us.

These quotations obviously supported the pattern 2.

The common rough graph is shown as below (Figure 9.3):

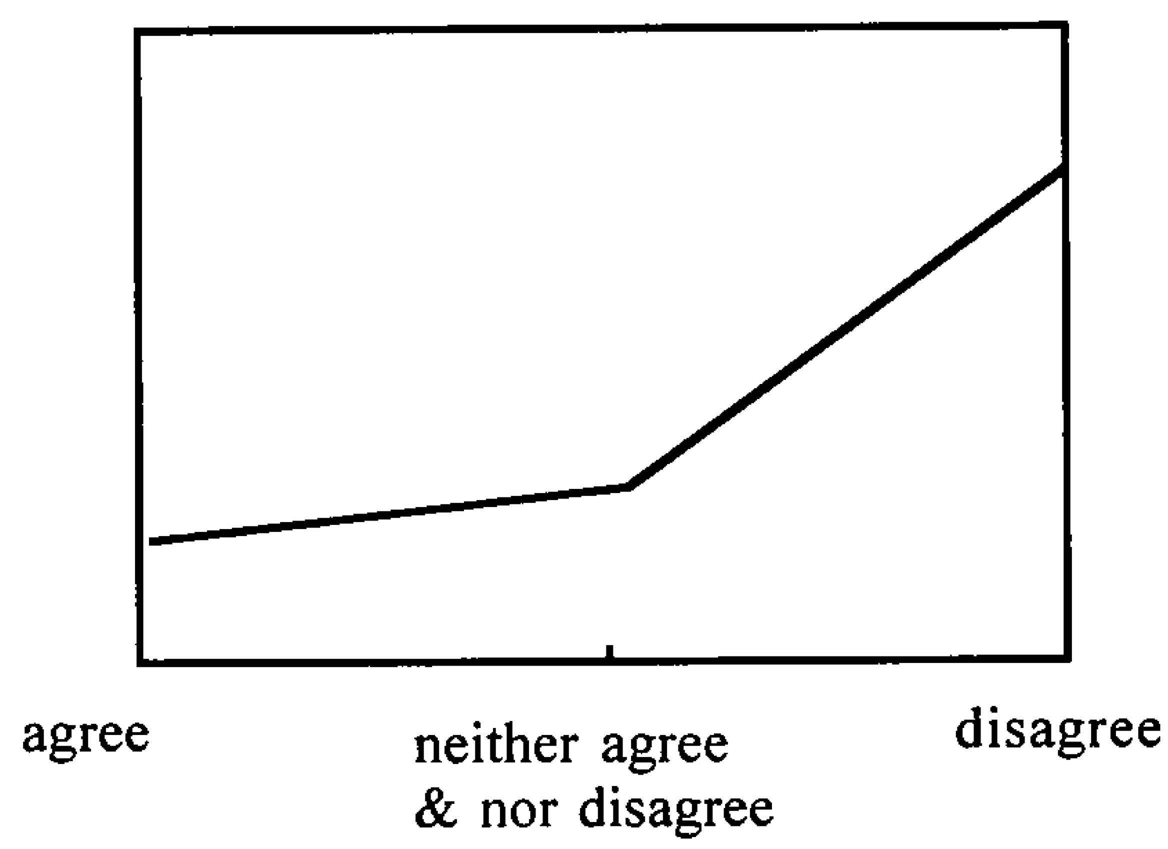


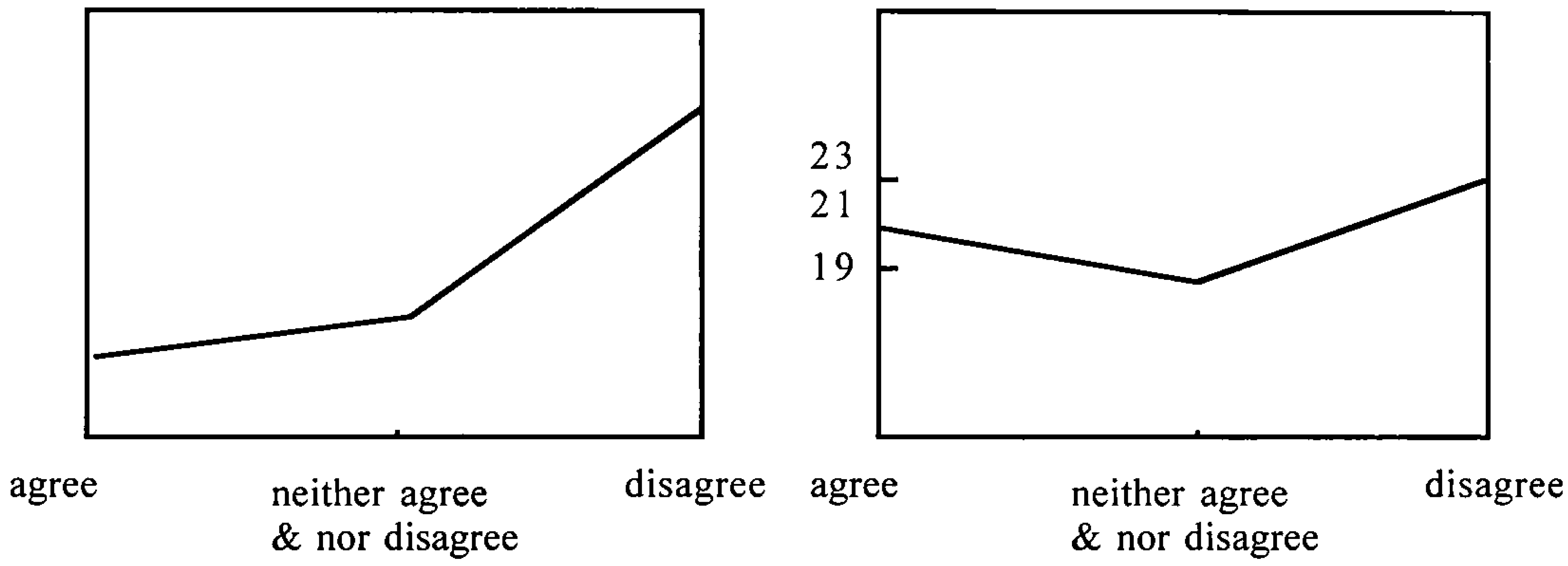
Figure 9.3 Question 5: The Common Graph

(III) ***Question 7: I prefer solving problems on my own***

Pattern 3: pupils did not prefer to work on their own (it is not obvious in unit 2 Taiwan).

Discussion: This pattern also can be supported by the opinions that pupils wrote in the open questions. One typical opinion (quoted from unit 8) is "*working in a group is a lot more helpful than trying to do it by myself*". However, the Taiwanese pupils did not have a clear cut opinion about unit 2, the numbers of "agree", "neither agree nor disagree" and "disagree" are almost equal. This might be due to the different culture which seldom encourages pupils to work together (except working in laboratory).

The common rough graph is shown as below (Figure 9.4):



(a) The common graph **(b) The graph of Unit 2 Taiwan**

Figure 9.4 Question 7: The Common Graph and the Specific Graph of Unit 2 Taiwan

(IV) ***Question 8: We worked well together as a group***

Pattern 4: pupils felt they had worked well as a group

Discussion: By observation, it is obvious that almost all pupils were engaged and involved in the group work and discussed well.

The common rough graph is shown as below (Figure 9.5).

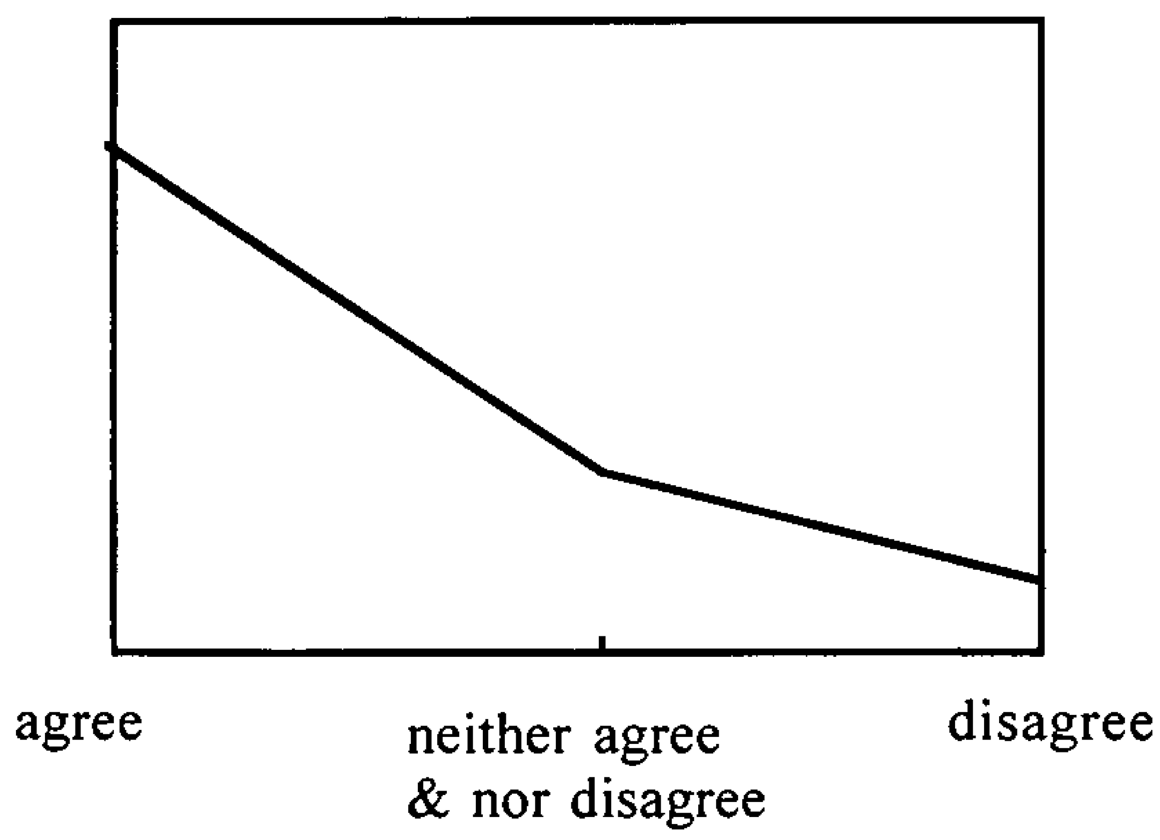


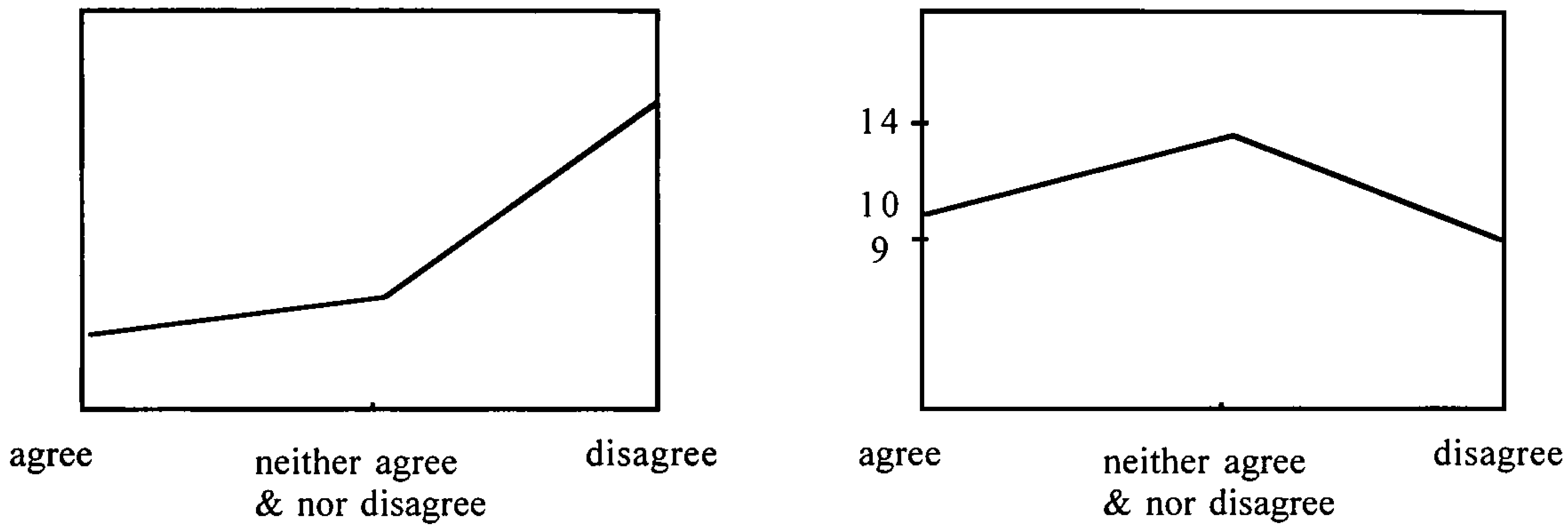
Figure 9.5 Question 8: The Common Graph

(V) ***Question 9*: *We did not share the work out evenly in our group***

Pattern 5: pupils felt they had shared the work out evenly (except unit 15).

Discussion: Similar to the question 8, this pattern also can be supported by observation. However, in unit 15, a different pattern emerged: the number of "disagree" is smaller (9) than the other two views (10 for agree, 14 for neutral). It means the pupils seem to think that they did not share the work out evenly. By reviewing the content of the unit 15, its main task involved much calculation work. It is possible that pupils could do the calculation individually, and this led them to communicate with their group members less than other units.

The common rough graph is shown as below (Figure 9.6):



(a) The common graph **(b) The graph of Unit 15**

Figure 9.6 Question 9: The Common Graph and the Specific Graph of Unit 15

(VI) ***Question 10*: *I found the group discussion helpful***

Pattern 6: pupils found that the group discussion helpful.

Discussion: Clearly pupils found group discussion helpful and this is consistent with observations of the groups as they worked. There was a high level of involvement and pupils talked freely about the problems. Again, some of the opinions expressed in the open questions also indicated that group discussions were much liked.

The common rough graph is shown as below (Figure 9.7):

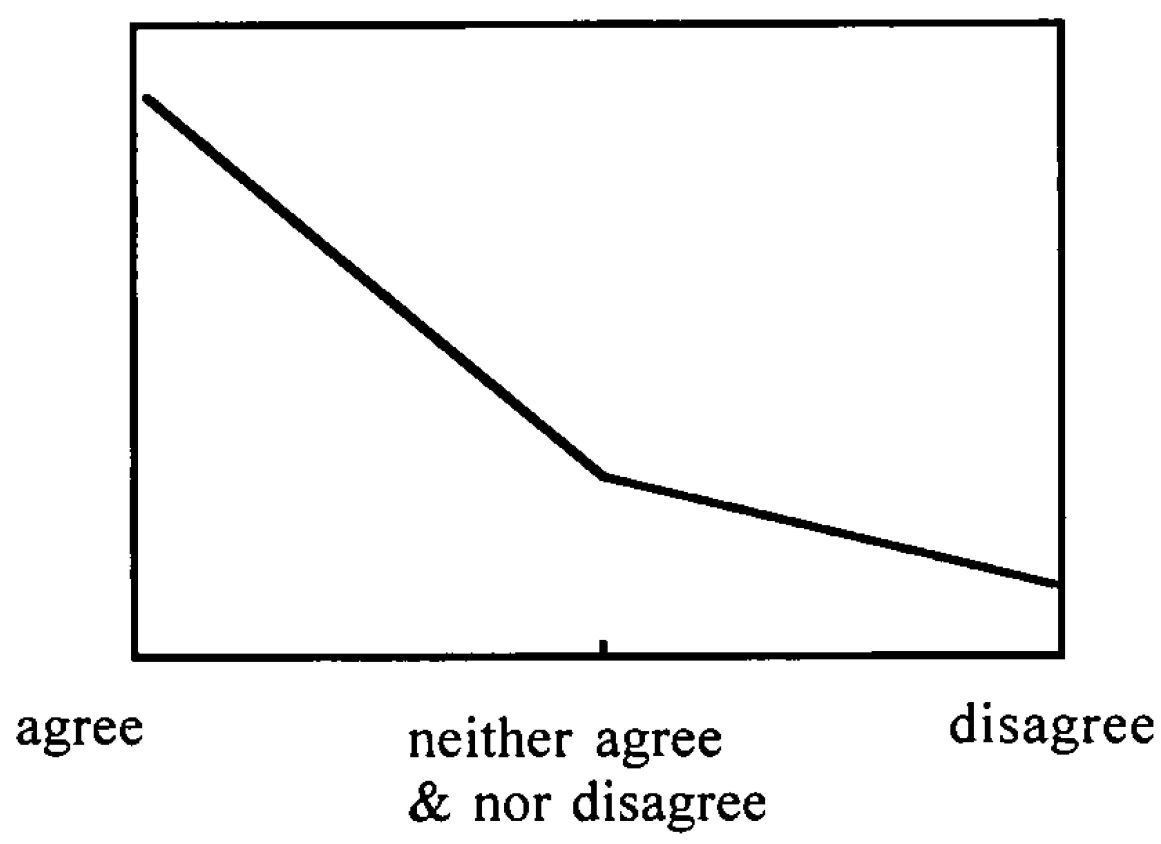


Figure 9.7 Question 10: The Common Graph

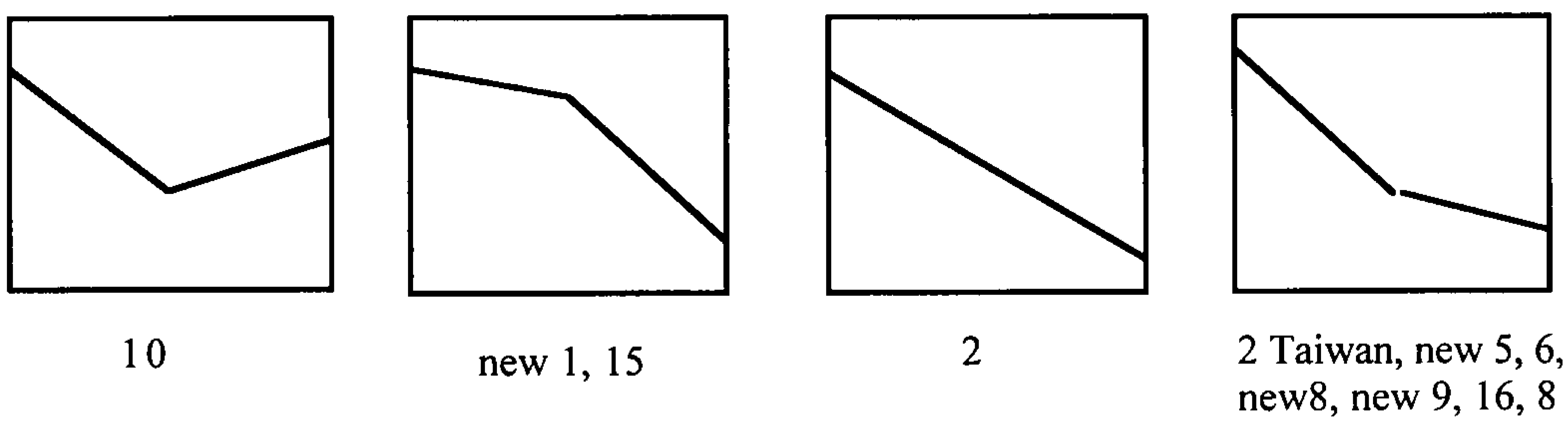
9.1.2 Specific Trends of Responses

In the following areas, there is a variety of patterns of responses, depending on the unit. While no common trends emerged among these questions, it is possible to relate the trends observed for the various units to features of the units and the way the pupils completed them. Each of these questions is discussed in turn.

(I) ***Question 1: The problem was enjoyable***

I.a The types of responses: There are 8 types of responses to this question, but they can be simplified and grouped into four patterns (Figure 9.8). The first pattern revealed that most units were regarded as enjoyable [new unit 1, 2, 2 (Taiwan), new 5, 6, 8, new 8, new 9, 10, 15, 16]. Secondly, pupils did not enjoy solving the problem in units 5, 9, 13. The third pattern is that pupils have a neutral response (roughly equal in expressing positive and negative views): this happened in units 1, 4, 12, 14. The final pattern is that pupils could not make a clear decision about "enjoyable": this only appeared in unit 8.

(a) Enjoyable patterns



(b) Other patterns

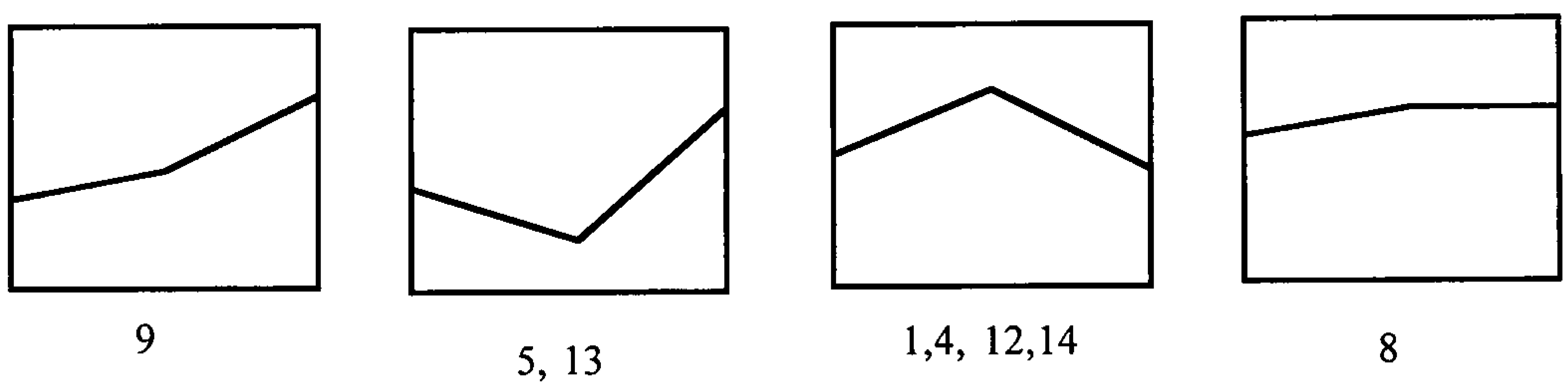


Figure 9.8 Question 1: The various Graphs

I.b Discussion: It is not surprising that responses to this question vary widely in that the units varied in content, difficulty and structure.

(II) *Question 2: The problem was difficult*

II.a The types of responses: There are 4 types of responses to this question, but they can be simplified and grouped into three patterns (Figure 9.9). The first pattern revealed that most units were regarded as difficult (except units 12 and unit 2 Taiwan). In unit 12, it was regarded as easy while, in unit 2 Taiwan, pupils gave a more neutral response.

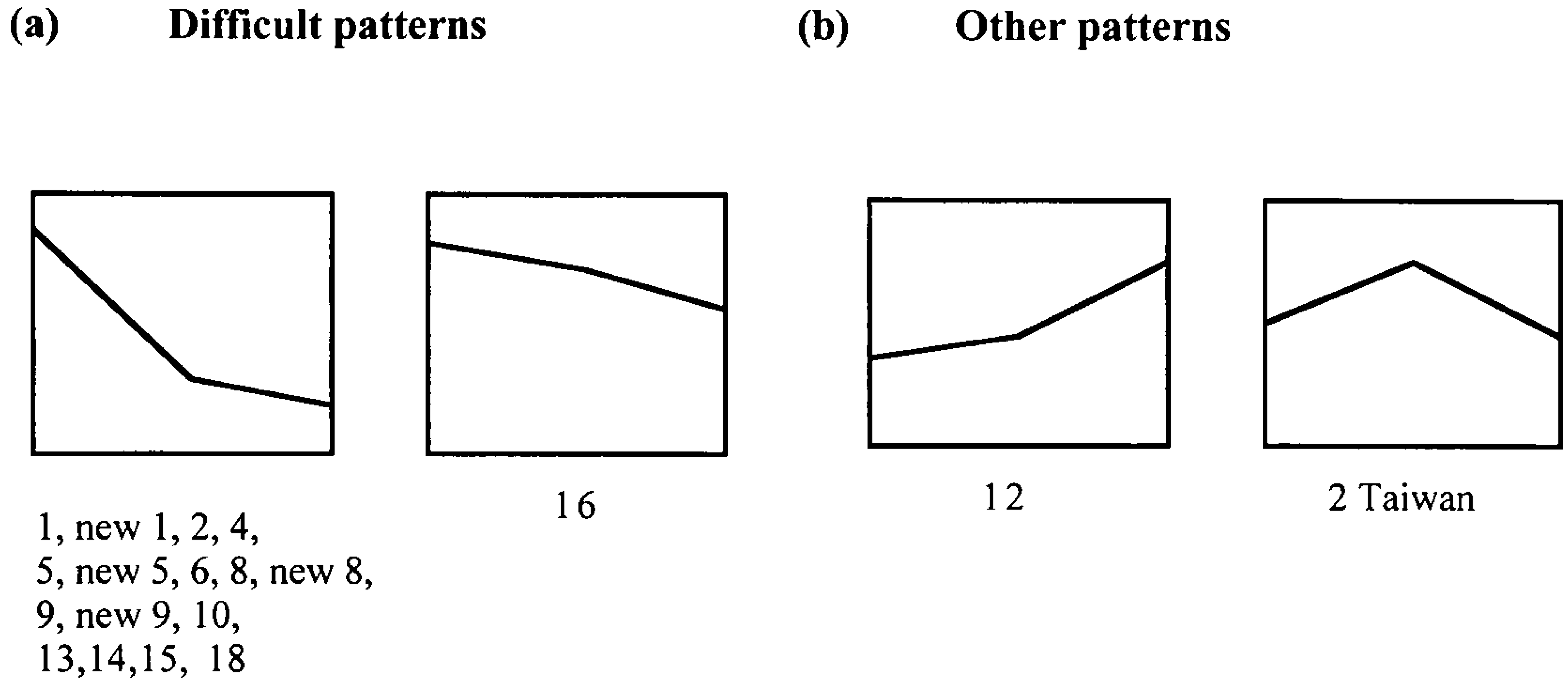


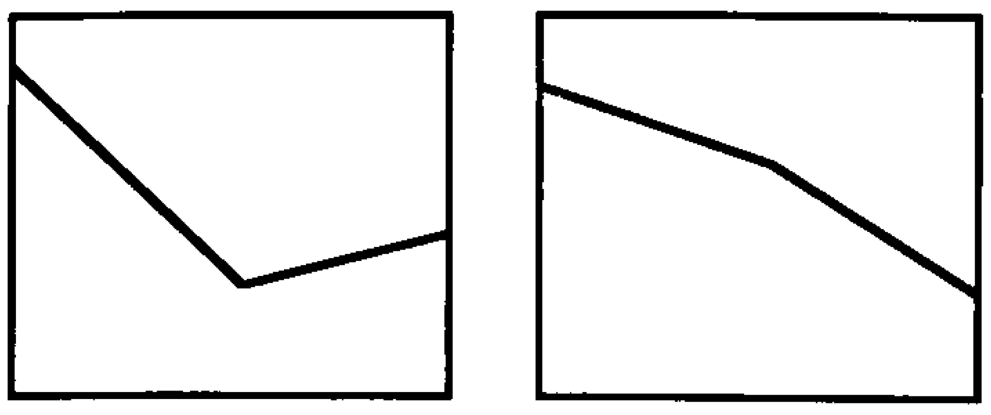
Figure 9.9 Question 2: The Various Graphs

II.b Discussion: In a similar way to enjoyment variations, difficulty levels are likely to vary widely. However, it is interesting to note that most units were regarded as difficult, and this is consistent with the intention of the project where, by using difficult problems, insights were sought into the character of these difficulties. It is also important to note that there is no relationship between perceived difficulty and the type of problem (following the Johnstone 8 type model). This is consistent with his original ideas where he never saw his eight types of problem as in any way hierarchical - they were merely different.

(III) *Question 3: I found that solving this problem was satisfying*

III.a The types of responses: There are 6 types of responses to this question, but they can be simplified and grouped into four patterns (Figure 9.10). The first pattern revealed that pupils were satisfied with solving most units (except unit 4, 5, 9,12, 13, 14). Secondly, pupils did not agree that solving the unit 9 problem was satisfying. The third pattern is that pupils have a neutral response: this happened in units 4, 12, 13, 14. The final pattern is that pupils could not make any clear decision about "satisfying": this only appeared in unit 5.

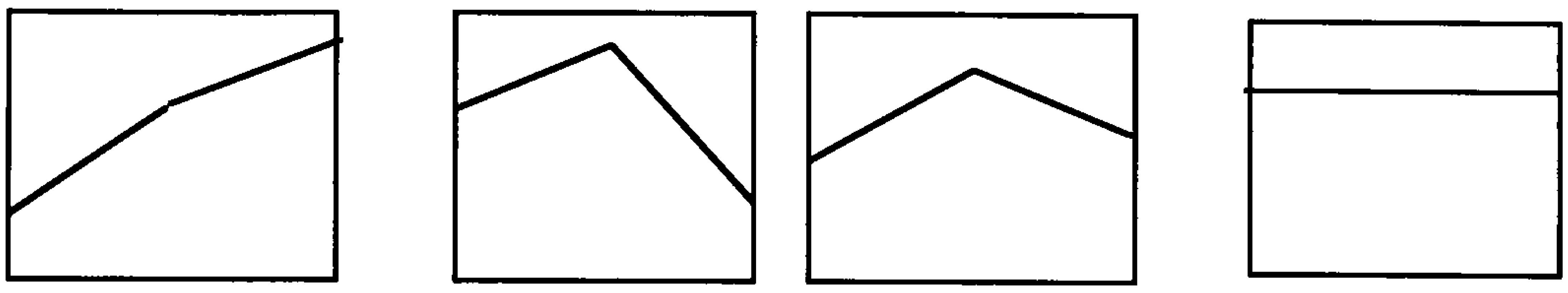
(a) Satisfying patterns



1, 2, new 5, 6 new 8, 15,

new 1, 2 Taiwan, 8, new 9, 10, 16, 18

(b) Other patterns



9 | 4, 14 | 12, 13 | 5

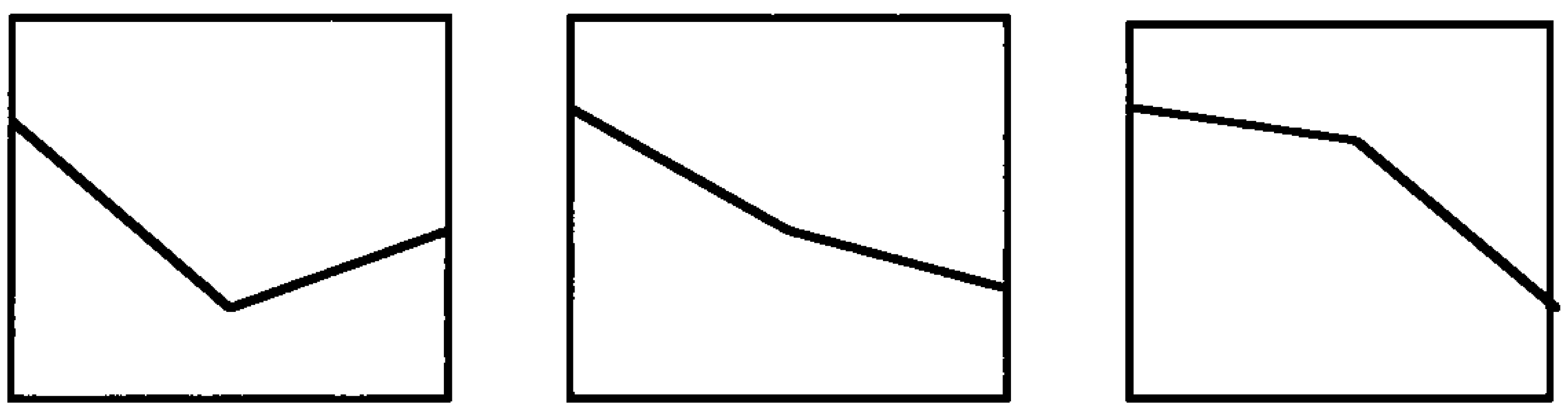
Figure 9.10 Question 3: The Various Graphs

III.b Discussion: It is to be expected that perceived satisfaction will vary from unit to unit.

(IV) *Question 6: I had enough previous knowledge to solve the problem*

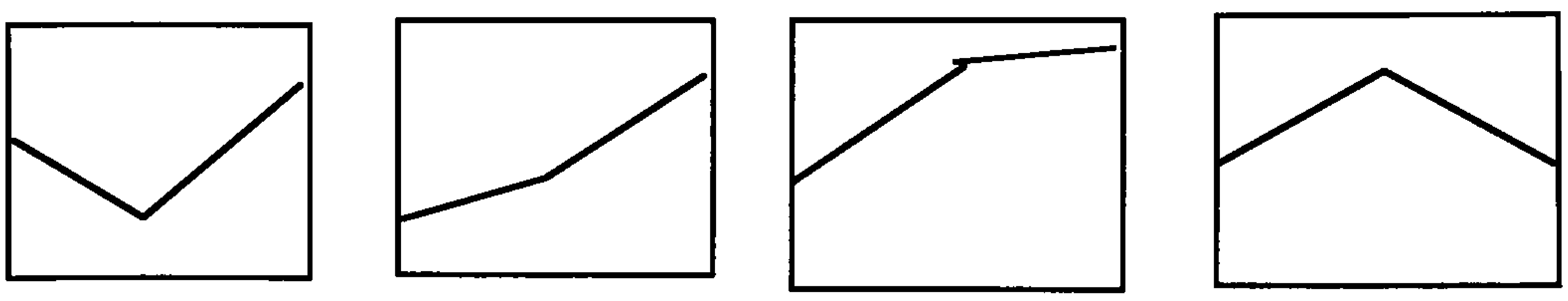
***IV.a The types of responses*:** There are 7 types of responses to this question, but they can be simplified and grouped into three patterns (Figure 9.11). The first pattern revealed that pupils felt they had enough previous knowledge to solve the following units: 1, new 1, 2, 5, new 5, 6, 15, 16, 18. Secondly, they did not think they had enough previous knowledge to solve the units: 4, 8, 9, new 9, 10, 12, 13, 14. The final pattern is that pupils have a neutral response which only happened in 2 Taiwan and new unit 8.

(a) Had enough previous knowledge patterns



1, 2 | new 1, new 5, 6, 15, 16, 18 | 5

(b) Other patterns



10, 12 | 8, 9, new 9, 13 | 4, 14 | 2 Taiwan, new 8

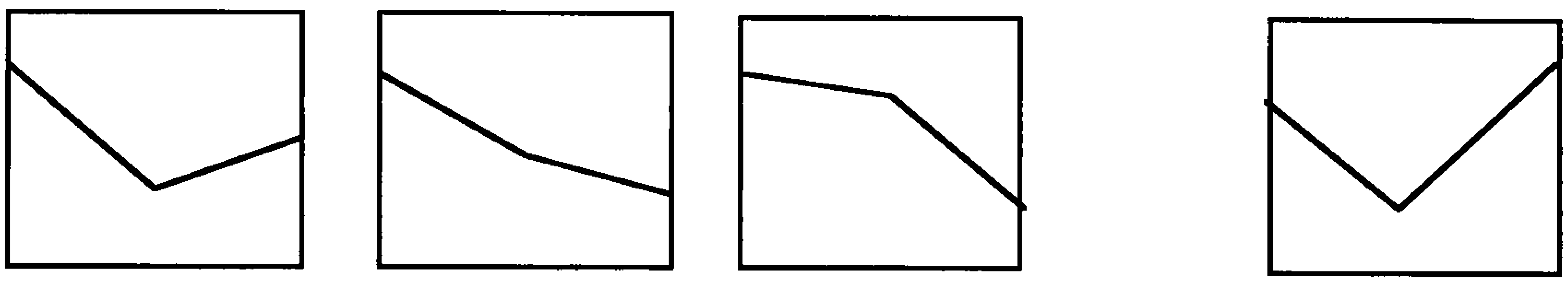
Figure 9.11 Question 6: The Various Graphs

IV.b Discussion: One of the main areas to be explored was the way previously held knowledge influenced problem solving success. In many units, pupils felt they had enough knowledge while, in others, they felt they did not know enough. However, success in the units does not seem to be related in any way to the pupils' perceptions about their previous knowledge.

(V) *Question 11: At the end, we were not sure we had the correct answer*

V.a The types of responses: There are 4 types of responses to this question, but they can be simplified and grouped into two patterns (Figure 9.12). The first pattern revealed that pupils were not sure about the answer in most units except the unit new 5 and unit 6. For these two units, pupils seem to be more confident about the answer.

(a) Not sure they have the right answer patterns **(b) Other patterns**



2, 5, 8, 9, new 9, 10, 13, 15 | 1, new 1, 4, new 8, 14,16,18 | 2 Taiwan, 12, | new 5, 6,

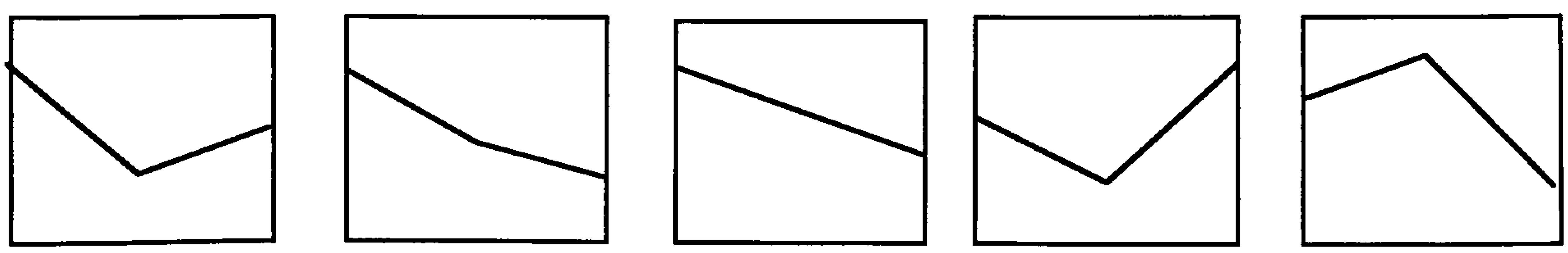
Figure 9.12 Question 11: The Various Graphs

V.b Discussion: In most units, pupils were not confident that they had the right answer. Perhaps this reflects the way chemistry is taught: there are "right" and "wrong" answers. In these units, such a view was difficult for pupils.

(VI) *Question 12: I could not have solved the problem by myself*

VI.a The types of responses: There are 5 types of responses to this question, but they can be simplified and grouped into three patterns (Figure 9.13). The first pattern revealed that pupils could not solve most of the problems individually except unit 6 and unit 12. For unit 12, they thought they could solve the problem individually. The final pattern is that pupils have a neutral response which only happened in unit 6.

(a) Could not solve problems individually patterns **(b) Other patterns**



new 1, 2, 5, 9 10, 13, 15, 16,18 | 2 Taiwan, 4, 8, new 8, new 9, 14 | 1, new 5 | 12 | 6

Figure 9.13 Question 12: The Various Graphs

VI.b Discussion: This supports the observation that group work was liked. It also reveals that pupils appreciated that they needed each other in order to solve such problems.

(VII) *Question 13: I needed the other group members to help me remember background information*

VII.a The types of responses: There are 4 types of responses to this question, but they can be simplified and grouped into two patterns (Figure 9.14). The first pattern revealed that pupils needed help from group members when they solved almost all units except unit 12. Another pattern is that pupils could not make clear decision in unit 12.

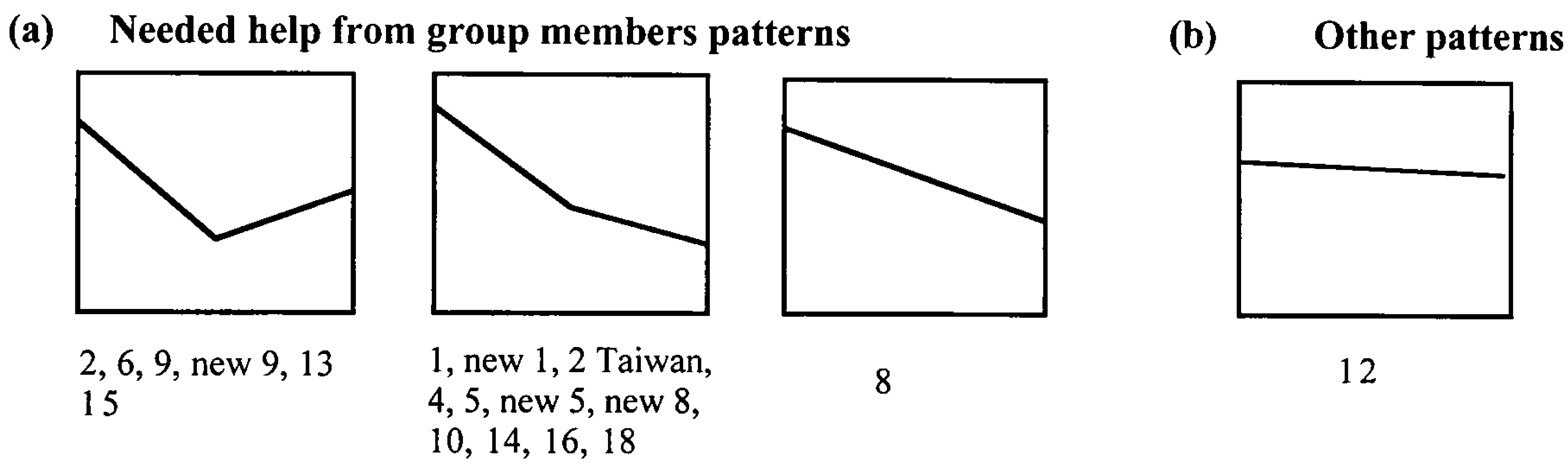


Figure 9.14 Question 13: The Various Graphs

VII.b Discussion: These patterns of results confirm the findings from question 12.

9.2 Correlations between Responses from the Thirteen Fixed Questions

In this project, each unit was attempted by a variable number of groups of pupils. It is possible to compare the responses from the thirteen fixed questions to see if there are correlations which might suggest useful insights. For example, using frequencies on the five point scale, questions 1 and 2, for unit 1, show the following patterns of responses.

Question 1:	Response pattern:	0	9	18	4	5
Question 2:	Response pattern:	6	16	7	7	0

The data are frequency data and distributions are not likely to be close to normal. In such circumstances, Kendal's Tau (τ) was employed. This statistic can handle very small samples sizes and makes no assumptions about distribution (Siegel, 1956).

The significance of these correlation coefficients (at 5% and 1%) for each unit is shown in Appendix H. A summary of the significant results is also listed in Appendix I.

The amount of data obtained is enormous (78 correlations for each unit, making over 1000 correlations overall). To simplify this and to seek clear patterns, the data for significant correlations is shown in Appendix H5. These significant correlations will be analysed and divided into three categories which are based on the number of units involved.

Category 1 In this category, 10 or more units show significant correlations between a pair of questions.

Category 2 In this category, 6 to 9 or more units show significant correlations between a pair of questions. As it reads, Category 2 would subsume Category 1 !!!

Category 3 Here, there are significant correlations between pairs of questions where there is inconsistency between various units.

The following sections discuss the findings.

9.2.1 Analysis of the Category 1

In this section, correlations between pairs of questions occur for at least 10 units. It is safe to assume that the correlations reflect a general characteristic of the units as a whole. All the observed correlations in this category confirm patterns which are totally to be expected. However, the expected results provide evidence of the validity of the responses.

Where units are enjoyable, then solving the problem is also satisfying. Lack of previous knowledge is a source of difficulty. Where the problem is new, the pupils feel they cannot solve it by themselves. Pupils with enough previous knowledge are more confident about the answer. Where a pupil does not have enough previous knowledge, he feels he cannot solve the problem by himself. Where pupils work well together, they will share the work out evenly. Where pupils cannot solve the problem by themselves, they will need the other group members to help him remember background information.

9.2.2 Analysis of the Category 2

In this section, correlations between pairs of questions occur commonly, noted for between 6 and 9 units. Again, most of the results are completely unsurprising.

Where pupils feel they are learning new things and work well together, their enjoyment tends to rise. Where problems are new, they feel that they cannot solve them on their own and that they are difficult. Learning new things tends to increase levels of satisfaction and feeling that they have enough knowledge to solve a problem also generates satisfaction. A problem's "newness" seems to be related to lack of knowledge in being able to solve it and this makes the pupils feel they need help from their peers.

Learning new things seems to be related to the way the group worked while lack of knowledge makes the individual more dependent on the group for help. Those who prefer solving problems on their own are less receptive to group work. Successful group work is related to the way the group shared out the work and pupils felt that they needed others , especially when they were unsure if they had a right answer.

9.2.3 Analysis of the Category 3

In quite a number of areas, contradictions were observed. In these cases, pairs of questions produced positive correlations for some units but negative correlations for others. In most cases, it is likely that this reflected specific features of the units but in one or two cases, it is possible that the inconsistency reflected something of of broader significance. This latter groups is now discussed.

It is interesting to note that when comparing perceived difficulty and enjoyment, most units show no correlations while some show negative correlations and one shows a positive correlation. It seems likely that enjoyment and difficulty are not neatly related, an observation made by Reid (1978) in a different context. There is a tendency to think that making things easy generates enjoyment but this is not a neat relationship.

A new problem is not always unenjoyable. This is probably linked to the observations about difficulty and enjoyment. Sometimes, the challenge of something new can produce enjoyment. It is similarly observed that enjoyment is not neatly linked to pupils preferences in seeking to solve problems on their own. Overall, enjoyment in an intellectual task such as this kind of open-ended problem solving is a complex perception and is easily linked to characteristics of the problem. However, in observing classes, one unit clearly showed very high levels of enjoyment. In this unit (16), there was a slight competive edge as they had to decide how to spend an imaginary £100. Again, this relates to previous work (Reid, 1978) which showed that enjoyment was highest with an edge of competitiveness.

In general, when pupils are unsure of they have a "right" answer, they tend to think of the problem as difficult. In one unit (15), this pattern was not observed and here, the problem was highly arithmetical and, thus, confidence in a "right" answer is increased.

When faced with situations where they felt that they had inadequate knowledge, the desire to work in a group was not always apparent. Usually, there was no relationship between interest in group working and knowledge inadequacy although in three units (8, 12, 16), the relationship did exist while in one unit (9), there was an inverse relationship. Group working cannot be seen, from the pupils' perspective, as a neat way to solve problems where the knowledge base is inadequate. Perhaps, in group work, there is a danger for some pupils that their weaknesses might be more apparent.

9.2.4 Overall Conclusions

Looking at the correlations obtained gives encouragement that pupils have responded to the questions in the way intended, suggesting that the measurements are valid. Few correlations gave useful insights. However, a few conclusions can be drawn:

While there was a strong tendency for pupils to enjoy the units, the basis for that enjoyment is not clear. Neither unit difficulty nor the fact that they were unfamiliar are related to enjoyment. In addition, there is no clear pattern suggesting that any type (using the eight types proposed by Johnstone) of unit is producing a higher level of enjoyment. However, the element of competitiveness does seem to raise enjoyment levels.

Pupils tended to perceive problems as difficult because the problems were unfamiliar and they felt they did not have enough knowledge. In fact, all the units were based specifically on the syllabus content and, therefore, pupils should have had enough knowledge. Nonetheless, they felt a knowledge inadequacy. This could be real or it might simply be that pupils were using the unfamiliar nature of the problems to suggest an excuse for difficulty in terms of lack of knowledge. However, this observation by the pupils might be linked to the lack of long term memory connections between islands of knowledge: while they should have known the key facts, perhaps the way they were required to link them to solve the problem was itself a major source of difficulty.

In many units, the difficulty is clearly related to the feeling of pupils that they were unsure that they had the "right" answer. This probably reflects the fact that the units were very different in character from their previous experiences where "right" answers may have been encouraged. Nonetheless, insecurity seems to be related to perceived difficulty.

Chapter Ten

Conclusions, Limitations and Recommendations

In this chapter, the results of this project will be reviewed and concluded briefly. As mentioned previously, problem solving is complex and influenced by many factors. Therefore, this project could not explore all the factors which might cause the problem solver failure or success. Some limitations of this project will be described. Finally, it is important to put emphasis on four important issues which are related to the future work and the implication for teaching problem solving.

10.1 Conclusions

This project involved 668 secondary pupils which ranging from S3 to S5 grade. The results obtained from observation, pupils' working answers, questionnaires, word association tests and tape recordings. The conclusions which including general and specific are shown as the following.

10.1.1 General Conclusions

It is clear that the units worked well with pupils and that most of pupils really enjoyed them. Some units were difficult (as planned) but pupils still held a positive attitude. When facing obstacles, very few just gave up. This might be a feature of group problem solving where they could share their ideas and support each other in groups. It is consistent with the observation that pupils liked working in groups.

If the goal was open, time demand increased. In addition, sometimes pupils knew less than expected but often did better than the teachers expected. It was also observed that clear leadership emerged only occasionally, but when it was present, it seemed to assist effective problem solving markedly. From the tape transcripts, pupil leaders could be identified clearly.

Finally, an interesting result was found in that the S5 pupils were very much better in discussion and had very much greater confidence than the S4 and S3 pupils. However, they were not much more successful in solving problems. Of course, S5 pupils were selected from those in S3 and S4, they had a much greater chemistry knowledge background, perhaps leading to a greater confidence in discussing the given task. Being older, they were also more socially mature.

10.1.2 Specific Conclusions

The used fourteen units covered four types of problems (types 3, 4, 5, 6). It was thought at the outset that the problem types might influence the pupils' performance on problem solving. However, the results show no clear evidence to suggest that the problems of "higher" categories were either more difficult or more demanding: the Johnstone model of problems does not seem to be hierarchical in any way.

Several specific conclusions are now discussed briefly.

(1) When solving a problem involving equations (eg. unit 9), it is clear that most pupils might be able to handle formula and equations but they seemed not really to understand what a formula in an equation can represent. This raises key questions about the representational aspects of chemistry. Equations can be interpreted at several levels and pupils, at this stage, find this difficult to grasp.

(2) Evidence suggests that by learning a procedure on one direction there is no guarantee that it can be applied in the opposite direction. This suggests that links in long term memory need to be made in both directions in order for the linkage to be soundly made.

(3) It has been suggested by some researchers such as Polya (1945) that devising a plan is an important skill which can lead to success in solving problem. In fact, it was found that pupils rarely planned; they just started with what they could do. Obviously, to organise information to make a plan seems to be difficult for these secondary pupils that might be due to unwillingness or inability. Nonetheless, the lack of planning was very evidence in the way they handled the problems, even when encouraged to to do so.

(4) When faced with an amount of unfamiliar information, pupils tended to lose confidence and seemed very unsure how to tackle a problem. The result has been addressed by Charles and Lester (1982) when they claimed that one of three interacting factors which included the familiarity with problem context and content can deter progress or prevent success in problem solving. In addition, an investigation was conducted by Raines (1984), the result also indicated that the least successful problem solvers failed to recognise problem similarity according to structure rather than context.

(5) Correct knowledge is vital for success in problem solving and this is consistent with the modification of Bloom's taxonomy shown on page 7. However, knowledge can be a hindrance if linked inappropriately. The results of unit 1 and unit 4 provided some evidence of knowledge side-tracking progress.

(6) One area of difficulty pupils frequently encountered is to bring various parts of information and knowledge together. It shows that the creation of a pathway between "islands" of knowledge or skills is extremely difficult. This was illustrated in open-ended problems such as unit 15 and unit 2. In unit 5, greater success occurred as a specific linking between catalysis and the breakdown of nitrogen dioxide was prompted. Therefore, it seems that learners cannot make linkages between key concepts and the links must be suggested or supplied by the teacher in some way.

(7) If the key concepts are partially grasped, then approaches to problem solving will be confused and the problem solver will not even be aware of the confusion. It can be seen from unit 4, where there is a lack of a clear grasp of the concepts of elements, compounds and bonding, that pupils started to generate explanations which mixed error with truth.

(8) In unit 8, in the second version, key pieces of data were deliberately brought together in the table of data. Despite this, pupils were no more successful. The difficulty in the problem does not appear to be based on perception.

(9) In unit 10, pupils seldom succeeded by using the common separation methods (despite they fact that they had been taught them) to obtain pure phosphorus. There were four unfamiliar compounds and the separation process is quite subtle, it demands a large amount of information derived from long term memory and operated in working memory space. Not surprisingly, the success was limited. In unit 13, the same problem happened again. A large amount data were provided to pupils and asked them to deduce a reasonable pattern: although pupils tried to reach the goal, most of them only made a superficial pattern. It seems in accord with one of the findings which were proposed by Johnstone and El-Banna (1986) that when the demand of the problem exceeded the working memory space, most pupils were not successful. Although this project tried to expand the limitation of working memory space by group work, the problem seemed to still occur in these two units.

(10) Pupils' unease and insecurity could occur when they faced with ambiguous data and with no unequivocal answer or approaches. Confidence is a very important factor in success in problem solving.

10.2 Limitations

There are two limitations in this project. Firstly, although the fourteen units covered types of 3, 4, 5 and 6 problems, most of the units are types 4 and 6. There were not enough units of types 3 and 5 problems. Therefore, it is difficult to make a clear comparisons and conclusions based on these four types of problems. Secondly, many different units had to be used to fit the teaching order in the various schools. Although this project involved 668 pupils, the numbers attempting each unit was relatively small. It is difficult to see easy ways to avoid such problems.

10.3 Recommendation

Watts (1994) argued that all problems ought to be difficult. If there is no obstacles for the problem solver to overcome, then the problem is not a real problem. If education wants to teach our pupils to be better problem solvers, it is important to find out the difficulty pupils frequently experience when they encounter a real problem and the strategies to help them overcome obstacles. Therefore, these eighteen units are suitable for school teachers to apply it in their class as a teaching resource.

Since the evidence from this project revealed that pupils are very positive with the group work in solving problem, it is suggested that group work should be widely employed to the field of learning and problem solving. As Wood (1993) claimed, several minds working jointly on a problem can produce solutions that individuals could not manage on their own.

There are several questions raised by the project. Can problem solving be taught? Is problem solving a genuine skill? These have been frequently questioned by many educators and researchers. Although Reif *et al* (1976) and Larkin and Reif (1979) have been developed general strategies for teaching problem solving in physics, they also agreed that problem solving cannot be taught easily. If the formation of key links between "islands" of knowledge is a key skill (and this project would support this), then it seems likely that problem solving is very much context dependent. Can the skill of linking be taught or is problem solving a skill that develops naturally as knowledge becomes more interlinked ? The individual with such links is confident and is willing to take risks to develop new links.

10.4 Suggestions for Further Research

Related to the limitation of this project and the outcomes of groups work, some suggestions for further research are offered below:

1. It could be helpful to develop other types of problem in order to make a clear comparisons and conclusions between Johnstone's eight types of problem. Does the same type of problems have the same difficulties with pupils? Or is the difficulty irrelevant to the types of problem ?

2. When pupils face a new type of problem, how do they make an appropriate linkage to solve problem shall be explored. Besides observation, it is possible to interview pupils to explore how the linkage develops when they work in groups.

3. In fact, a leader appearing in a group may influence the group discussion. Can the leadership of group work help pupils to make an appropriate linkage?

4. By developing teaching experiences in problem solving where the level of difficulty steadily rises, is it possible to find strategies to enhance the skills of problem solving in chemistry ?

5. Is there any evidence that the development of problem solving skills in chemistry allows the learner to solve problems better in other areas or is problem solving essentially a context-limited skill ?

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List of Appendices

Appendix A

Eighteen Chemistry Units

1

Argon and Electric Welding

Your Name: ....

This report appeared in *The Star Ledger.*

Two workmen were suffocated in a tragic industrial accident when they were overcome by fumes in a large tank where electrical-welding was taking place. Afterwards, a detective said that "burning argon gas in the welders torch apparently used up all the oxygen in the tank".

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Discuss this report as a group, looking for chemical mistakes and possible explanations for the tragedy.

Re-write the detective's explanation on your answer sheet so that it is a reasonable explanation for the tragedy.

Use this space for any notes, calculations, working etc.

1

Argon and Electric Welding (Revised)

Your Name: ....

This report appeared in *The Star Ledger.*

Two workmen were suffocated in a tragic industrial accident when they were overcome by fumes in a large tank where electrical-welding(welding where the heat to melt metal comes from a electrical spark) was taking place. Afterwards, a detective said that "burning argon gas in the welders torch apparently used up all the oxygen in the tank".

You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Discuss this report as a group, looking for chemical mistakes and possible explanations for the tragedy.

Re-write the detective's explanation on your answer sheet so that it is a reasonable explanation for the tragedy.

Use this space for any notes, calculations, working etc.

2

Which is the Best Fuel ?

Your Name: ....

There are three important fuels which can give you energy.

(1) Coal - which contains the element carbon, C
(2) Oil - a hydrocarbon mixture, mainly $C_{11}H_{24}$
(3) Gas - mainly methane, CH_4

Which of these is likely to give you the most energy ?

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Part 1

Write balanced equations for the complete combustion of each fuel. Make sure you agree on the answers before filling in your answer sheet.

Part 2

Calculate the formula masses of each of the fuels. Write down your agreed answers.

C = 12, H = 1

Part 3

Assume that the energy released is related to the number of molecules formed. In other words, the more molecules formed, the greater the energy released.

Suppose you were given 1 Kg (=1000g) of each fuel, which fuel would give you most energy?

Discuss, as a group, how you might tackle this problem before you start.

You won't need to use a calculator - just carry out rough calculations.

Part 4

You were told to assume that the energy released is related to the number of molecules formed. Is this a fair assumption ? Write down the thoughts of your group on your answer sheet.

Use this space for any notes, calculations, working etc

3

The Chewing Gum Problem

Your Name: ....

People have chewed gum-like substances to freshen their breath and clean their teeth for centuries. Some people think that chewing gum not only freshens the breath but it also cleans the teeth and helps to free them from decay.

Let's look at tooth decay. Does gum-chewing really help to keep teeth healthy?

Here's a list of what is in chewing gum:

(1)	Chewing gum base:	a synthetic rubber-like substances
(2)	Sweeteners:	sugar (sucrose) or sugar substitutes (like those used in diet coke)
(3)	Softeners:	vegetable oil products like glycerine (glycerol)
(4)	Flavourings:	spearmint and peppermint oils

You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

(1) What do you think is the difference between ordinary gum and "sugar-free" gum?

(2) After eating, bacteria will attack and break down carbohydrates like starch and sucrose (cane sugar). Try to write down as much as you can about the process in which carbohydrate is broken down in the mouth.

(3) We want to find out if the practice of using chewing gum helps to fight tooth decay or not. Discuss what information you need to reach an answer based on your knowledge of the way carbohydrates are broken down. Make a list of what you need to know.

Use this space for any notes, calculations, working etc

4

Fluoride Improves Tooth Decay ?

Your Name: ....

The following item appeared in a magazine article on tooth decay.

> Fluoride strengthens teeth by bonding with calcium, the main ingredient in enamel, to form calcium fluoride. Calcium fluoride is a harder, denser material than calcium alone, making teeth more resistant to the bacteria that cause decay.

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

This statement contains a number of errors.

Discuss the statement and then list as many errors as possible on your group answer sheet.

Use this space for any notes, calculations, working etc

4

Fluoride Improves Tooth Decay ? (Revised)

Your Name: ....

The following item appeared in a magazine article on tooth decay.

> Fluoride strengthens teeth by bonding with calcium, one of the ingredients in enamel (% of calcium in enamel is 16.6%) , to form calcium fluoride. Calcium fluoride is a harder, denser material than calcium alone, making teeth more resistant to the bacteria that cause decay.

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your <u>agreed</u> answers on to the "Answer Sheet".

This statement contains a number of errors.

<u>Discuss</u> the statement and then <u>list</u> as many errors as possible on your group answer sheet.

Use this space for any notes, calculations, working etc

5

The Glowing Splint Problem

Your Name: ....

You will be working in a small group. Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Part 1

In a car engine, some nitrogen dioxide is formed and can come out in the exhaust fumes. As a group, discuss possible answers to the following questions:

(a) Explain how the gas nitrogen dioxide (NO_2) is formed in a car engine.
(b) What problems can NO_2 cause ?
(c) How can the problem of NO_2 be solved in a car ?
(d) When the NO_2 is removed from the car exhaust, what gases are formed ?

Part 2

Experiments have shown that:

(i) Oxygen re-kindles a glowing splint
(ii) Neither air nor NO_2 will re-kindle a glowing splint.
(iii) Air contains approximately 20% oxygen.

Now look at the following experiment:

Copper (II) Nitrate breaks up when heated to give copper (II) oxide, nitrogen dioxide and oxygen. The balanced equation is:

$$2Cu(NO_3)_2 \xrightarrow{\text{heated}} 2CuO + 4NO_2 + O_2$$

The gases coming out of the test tube contain 80% nitrogen dioxide and 20% oxygen but it is found that they will re-kindle a glowing spint.

Look at all the information given to you. Working as a group, discuss possible answers to the following questions:

(1) Why is this an unexpected result ?
(2) Can you suggest a possible explanation for this ?

Use this space for any notes, calculations, working etc

5

The Glowing Splint Problem (Revised)

Your Name: ....

You will be working in a small group. Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Nitrogen dioxide (NO_2) is a gas which can be found in car exhaust fumes. It can be broken up in the car exhaust.

Question to discuss: When the NO_2 is broken up in the exhaust, what gases are formed ?

****

Experiments have shown that:

(i) Air contains approximately 20% oxygen plus 80% nitrogen.
(ii) Oxygen re-kindles a glowing splint.
(iii) Neither air nor NO_2 will re-kindle a glowing splint.

Now look at the following experiment:

Copper (II) Nitrate breaks up when heated to give copper (II) oxide, nitrogen dioxide and oxygen. The balanced equation is:

$$2Cu(NO_3)_2 \xrightarrow{\text{heated}} 2CuO + 4NO_2 + O_2$$

The gases coming out of the test tube contain 80% nitrogen dioxide and 20% oxygen but it is found that they will re-kindle a glowing spint.

Look at all the information given to you. Working as a group, discuss possible answers to the following questions:

(1) Why is this an unexpected result ?
(2) Can you suggest a possible explanation for this ?

Use this space for any notes, calculations, working etc

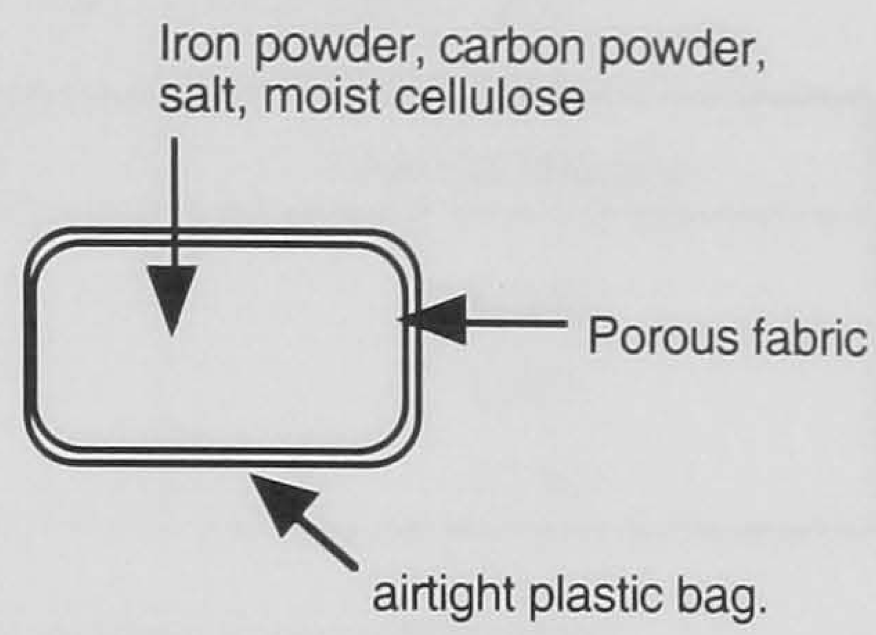
6 Heat packs for Mountaineers

Your Name: ....

There is always the possibility of being caught in bad weather when climbing in Scottish hills. Those who climb mountains often carry heat packs to provide quick heat energy in case of severe cold.

The heat packs consists of a small packet made from porous fabric.
This packet is contained in an outer, airtight plastic bag.
In the packet, there is:

(a) very fine iron powder (the main material)
(b) very fine carbon powder
(c) salt
(d) moist cellulose (like damp blotting paper)



The following directions are given for using the heat packs.

Open the outer plastic bag. Remove the inner packet. Rub it with your hands several times, then hold the packet in your hand. It will keep at a comfortable temperature (about 60°C) and will last for about 6 hours.

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

The heat pack produces its heat by means of a chemical reaction. Look very carefully at all the information given. As a group, discuss this information and what it tells you about how the heat pack might work.

(1) Work out how the heat packs works and explain where the heat energy comes from ?

(2) Why is iron powder used as the main material for the heat packs ?
Suggest any other powdered metal that might be used, giving reasons for your choice.

Use this space for any notes, calculations, working etc

7

Iron: How can we Obtain it ?

Your Name: ....

There is almost no iron metal to be found on the earth. Iron combines with other elements too easily and is found in various compounds. These are known as iron ores and there are three common ores: iron pyrites, magnetite, haematite.

Look at the table below. It shows the percentage of Iron in each ore and the rough cost of each ore.

Iron ores	Formula	% of Iron in the ore	Cost of the ore
Magnetite	Fe_3O_4	55-65	£125
Haematite	Fe_2O_3	50-65	£105
Iron pyrites	FeS_2	30-40	£110

You will be working in a small group. Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Imagine you are to manage a factory which converts iron ore into iron metal.

Working as a group, discuss possible answers to the following:

(1) Look at the table above. As a group, discuss which of the three ores listed you prefer to use in your factory.

(2) The process in your factory involves heating the iron ore with carbon (coal) at a very high temperature. This is done in a blast furnace. There are three main reactions:

(a) The production of carbon monoxide which reacts with iron ore to release iron.
(b) The conversion of iron oxide into iron metal.
(c) The removal of impurities like sand (silicon dioxide) using limestone.

The raw material of the process is a mixture of iron ore, coke, limestone and air.

Here are several chemical equations. Select the equations that describe what is going on in your factory and re-arrange them in a sequence that seems reasonable.

1. $C(s) + O_2(g) \rightarrow CO_2(g)$
2. $2C(s) + O_2(g) \rightarrow 2CO(g)$
3. $CO_2(g) + C(s) \rightarrow 2CO(g)$
4. $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$
5. $CaO(s) + SiO_2(s) \rightarrow CaSiO_3(l)$
6. $Fe_2O_3(s) + CO_2(g) \rightarrow 2FeO(s) + CO(g) + O_2(g)$
7. $4FeS_2(s) + 11O_2(g) \rightarrow 2Fe_2O_3(s) + 8SO_2(g)$
8. $Fe_3O_4(s) + CO(g) \rightarrow 3FeO(s) + CO_2(g)$
9. $Fe_2O_3(s) + CO(g) \rightarrow 2FeO(s) + CO_2(g)$
10. $FeO(s) + CO(g) \rightarrow Fe(l) + CO_2(g)$

(3) List all the gases produced in your factory. Are these safe to release to the atmosphere ?

Use this space for any notes, calculations, working etc

8

Moving Gases

Your Name: ....

Have you ever smelled the perfume from someone immediately after they entered the room ? This is because the particles of perfume are travelling through the air and have reached your nose. All gases travel but they do not all travel at the same speed. It has been found that different gases travel different distances in the same time.

The following data were collected from an experiment. The distances travelled by various gases in a set amount of time through a horizontal glass tube were observed. This was done at room temperature and the same pressure for all the gases.

Gas	Distance (cm)
SO_2	50
HCl	66
CH_4	100
SO_3	44
NH_3	94

You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Working as a group,

(1) Look at the results as a group and see if you can spot any pattern in these results ?

(2) How would you test to see if your pattern is correct ?

(3) Predict how far you would expect chlorine gas (Cl_2) to travel under the same conditions.

H	=	1
C	=	12
N	=	14
O	=	16
S	=	32
Cl	=	35.5

Use this space for any notes, calculations, working etc

8

Moving Gases (Revised)

Your Name: ....

Have you ever smelled the perfume from someone immediately after they entered the room ? This is because the particles of perfume are travelling through the air and have reached your nose. All gases travel but they do not all travel at the same speed. It has been found that different gases travel different distances in the same time.

The following data were collected from an experiment. The distances travelled by various gases in a set amount of time through a horizontal glass tube were observed. This was done at room temperature and the same pressure for all the gases.

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SO_3	44
NH_3	94

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Cl	=	35.5

Use this space for any notes, calculations, working etc

9

The Formula for Ozone

Your Name: ....

We hear about ozone gas frequently in the news. To find out what ozone is, we shall first look at several other gases.

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Part 1

Look at the following reactions:

(a) $2NH_3 \longrightarrow N_2 + 3H_2$

(20ml) → (40ml)

20ml of ammonia breaks down to give 40ml of a mixture of nitrogen and hydrogen

(b) $H_2 + Cl_2 \longrightarrow 2HCl$

(20ml) → (20ml)

20ml of a 50:50 mixture of hydrogen and chlorine reacts to give 20ml of hydrogen chloride gas

(1) If you started with 20ml of a 50:50 mixture of carbon monoxide and hydrogen, can you work out what volume (in ml) of formaldehyde (CH_2O) will be produced in the following reaction ?

$$CO + H_2 \longrightarrow CH_2O$$

(20 ml) → (?)

(2) Can you work out what volume (in ml) of carbon dioxide will be produced in the following reaction ?

$$2CO + O_2 \longrightarrow 2CO_2$$

(30ml) → (?)

At this stage, check your answers with your teacher.

Part 2

Ozone is a gas. In a series of experiments, it can be shown that, for every 20ml of ozone that break up, 30 ml of oxygen is formed. Surprisingly, no other element is involved.

Ozone (20ml) ⟶ Oxygen (30ml)

Given that the formula for Oxygen is always O_2, can you work out the likely formula for Ozone ? How did you find out your answer ? Write down your group's way of finding the answer on your answer sheet.

Use this space for any notes, calculations, working etc

9

The Formula for Ozone (Revised)

Your Name: ....

We hear about ozone gas frequently in the news. To find out what ozone is, we shall first look at several other gases.

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Part 1

Look at the following reactions, shown by balanced equations:

(a) $2NH_3 \longrightarrow N_2 + 3H_2$
(20ml) → (40ml)

20ml of ammonia breaks down to give 40ml of a mixture of nitrogen and hydrogen

(b) $H_2 + Cl_2 \longrightarrow 2HCl$
(20ml) → (20ml)

20ml of a 50:50 mixture of hydrogen and chlorine reacts to give 20ml of hydrogen chloride gas

(1) Can you work out what volume (in ml) of carbon dioxide will be produced in the following reaction ?

$2CO + O_2 \longrightarrow 2CO_2$
(30ml) → (? ml)

(2) At about 450° C, phosphorus gas breaks up according to the following equation:

$P_4(g) \longrightarrow ?$
(20 ml) → (40ml)

What is the formula of phosphorus gas above 450° C ?

At this stage, check your answers with your teacher.

Part 2

Ozone is a gas. In a series of experiments, it can be shown that, for every 20ml of ozone that break up, 30 ml of oxygen is formed. Surprisingly, no other element is involved.

Ozone $\longrightarrow$ Oxygen
(20ml) → (30ml)

Given that the formula for Oxygen is always O_2, can you work out the likely formula for Ozone ? How did you find out your answer ? Write down your group's way of finding the answer on your answer sheet.

Use this space for any notes, calculations, working etc

10

The Phosphorus Problem

Your Name: ....

Phosphorus is made in industry from rock phosphate which has the following complicated formula:

$$3Ca_3(PO_4)_2.CaF_2$$

The reaction is:

$$3Ca_3(PO_4)_2.CaF_2\,(s) \xrightarrow[SiO_2]{1500°C} CaSiO_3(s) + CO(g) + P_2\,(g) + SiF_4(g)$$

When heated to a temperature of 1500°C with carbon (coke) and silicon dioxide (sand), the following gases are produced:

CO P_2 SiF_4

In the reaction furnace, there are four main products and the problem is to separate them in order to obtain pure phosphorus. The difficulty is that phosphorus catches fire immediately on contact with air.

Here is some information to help you:

Compound	Melting Point (°C)	Boiling Point (°C)	Reaction with Water	Reaction with Air	Density (gcm^{-3})
$CaSiO_3$	~1540	Not known	Insoluble, no reaction	None	2.9
CO	-199	-191	Insoluble, no reaction	Burns	1.25
P_2	44	280	Insoluble, no reaction	Burns violently	1.82
SiF_4	-90	-86	Reacts *	Reacts with dampness in air*	4.69

* The reaction is: $SiF_4(g) + H_2O(l) \longrightarrow SiO_2(s) + HF(aq)$

You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your <u>agreed</u> answers on to the "Answer Sheet".

Try to work out a way to obtain <u>pure phosphorus solid</u> which is uncontaminated by the other three products. Remember that the phosphorus must always be kept away from air. [You may find out helpful to use pictures or diagrams.] Write down your agreed answers on your answer sheet.

Use this space for any notes, calculations, working etc

11

The Leaking Pipe

Your Name: ....

An explosion resulting from a leaking underground pipeline was reported in a local newspaper.

A Department of Public Safety spokeswoman said, "Authorities suspect gas collected in a low-lying ravine was ignited by a passing vehicle or possibly by a pilot light in a nearby home. The pipeline carried liquefied propane gas, often called LP gas. Natural gas liquids turn to gas when they come in contact with air."

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Look carefully at the statement.

(1) List the errors and misunderstandings that the spokewoman has.

(2) In your own words, re-write the statement so that is correct .

Use this space for any notes, calculations, working etc

12 Salt, Salts, and pH

Your Name: ....

When you use the word "salt", you probably think of sodium chloride, the white subtsance you put on your chips. However, sodium chloride is just one of a huge number of compounds that are known as "salts". Salts are usually made up of a metal 'bit' and a 'bit' that comes from an acid. Not all salts will dissolve in water but here is a list of some salts and the pH of the solutions obtained by some pupils when they dissolved them in water.

Salt	pH
Iron (II) sulphate	1
Aluminium chloride	3
Zinc (II) sulphate	3
Copper (II) nitrate	3
Sodium chloride	7
Potassium sulphate	7
Calcium chloride	7
Sodium nitrate	7
Sodium carbonate	10
Potassium carbonate	11

You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Your Task

It is possible to draw many conclusions from the above table.
For example, salts containing potassium (K) always seem to have a pH of 7 or more.
We say that the pH $\geq$ 7.

Working as a group, see how many other conclusions you can draw from the table of results. Write down your agreed answers.

Use this space for any notes, calculations, working etc

13

Solubility

Your Name: ....

Different compounds tend to dissolve in water to different extents.

Here is a table of solubility of some salts, expressed in grams per 100 grams of solution at room temperature.

	OH^-	F^-	Cl^-	CO_3^{2-}	NO_3^-	SO_4^{2-}
Na^+	109	4	36	21	87	19
K^+	112	95	35	112	32	11
Mg^{2+}	0.0009	0.008	54	0.011	70	33
Ca^{2+}	0.16	0.0016	75	0.002	129	0.21
Ba^{2+}	14	0.12	36	0.002	9	0.0002
Pb^{2+}	0.016	0.064	0.99	0.001	55	0.004
Zn^{2+}	0.85	1.62	420	0.001	184	96
Ag^+	decomposes	195	0.0001	0.003	217	0.8
Fe^{2+}	0.0002	not known	70	0.007	84	20

Compounds can be divided into three groups:

Giving more than 10 g in 100 g of solution are called: "soluble"
Giving less than 1 g in 100 g of solution are called: "insoluble"
Giving between 1g and 10g in 100g of solution are called: "slightly soluble"

You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

(1) Can you see any patterns in these results ? As a group, write down as many patterns as you can.

(2) If you were to mix a solution of magnesium chloride with a solution of potassium hydroxide, predict what might happen. Write down your agreed answer.

(3) A solution contains a mixture of lead nitrate and sodium nitrate. Try to work out a way to obtain a solution containing only sodium nitrate. Write a description of your agreed answer.

(4) You have been given the information about compounds of magnesium, calcium and barium. Look at your periodic table. You can see the element strontium (which is less common but was found first in Scotland). Using the table of information, predict the approximate solubility that you would expect for strontium hydroxide and strontium sulphate. Write down your agreed answers.

Use this space for any notes, calculations, working etc

13 Solubility (Revised)

Your Name: ....

Different compounds tend to dissolve in water to different extents.

Here is a table of solubility of some salts, expressed in grams per 100 grams of solution at room temperature.

	OH^-	F^-	Cl^-	CO_3^{2-}	NO_3^-	SO_4^{2-}
Na^+	109	4	36	21	87	19
K^+	112	95	35	112	32	11
Mg^{2+}	0.0009	0.008	54	0.011	70	33
Ca^{2+}	0.16	0.0016	75	0.002	129	0.21
Ba^{2+}	14	0.12	36	0.002	9	0.0002
Pb^{2+}	0.016	0.064	0.99	0.001	55	0.004
Zn^{2+}	0.85	1.62	420	0.001	184	96
Ag^+	decomposes	195	0.0001	0.003	217	0.8
Fe^{2+}	0.0002	not known	70	0.007	84	20

Compounds can be divided into three groups:

Giving more than 10 g in 100 g of solution are called: "soluble"
Giving less than 1 g in 100 g of solution are called: "insoluble"
Giving between 1g and 10g in 100g of solution are called: "slightly soluble"

You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

(1) Can you see any patterns in these results ? As a group, write down as many patterns as you can.

(2) You have been given the information about compounds of magnesium, calcium and barium. Look at your periodic table. You can see the element strontium (which is less common but was found first in Scotland). You have not been given any information about strontium. Using the table of information, predict the approximate solubility(using numbers) that you would expect for strontium hydroxide and strontium sulphate. Write down your agreed answers.

(3) If you were to mix a solution of magnesium chloride with a solution of potassium hydroxide, predict what might happen. Write down your agreed answer.

Use this space for any notes, calculations, working etc

14

The Swimming Pool Problem

Your Name: ....

Helen, Paul and James swam in the local swimming pool. They all found the smell of the water to be unpleasant and, afterwards, they had sore eyes. Helen's father was a doctor and he not only gave them some soothing eye ointment but he also advised them about what was added to swimming pool water.

He said: "One of the additives in the water is chlorine. When it is added to water, it will produce hypochlorous acid. The molecules of the acid can penetrate the bacteria in the water and kill them. But the acid also can react with other substances to give substances with nasty smells. Some of them can irritate your eyes."

Helen, Paul and James did not fully understand all that Helen's father had said. As a group, can you help them to understand what was the problem ?

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Part 1

List what you think might be the desirable properties for swimming pool water so that it is pleasant and safe for public swimming.

Part 2

Chlorine reacts with water to give two compounds which are hydrochloric acid (HCl) and hypochlorous acid (HOCl):

$$Cl_2(g) \quad + \quad H_2O(l) \longrightarrow HCl(aq) \quad + \quad HOCl(aq)$$

In addition, hydrochloric acid and hypochlorous acid form ions in water

(a) Write possible equations for the ionisation of each.

(b) What do you think happens to the pH of the water in the swimming pool when it is chlorinated?

Part 3

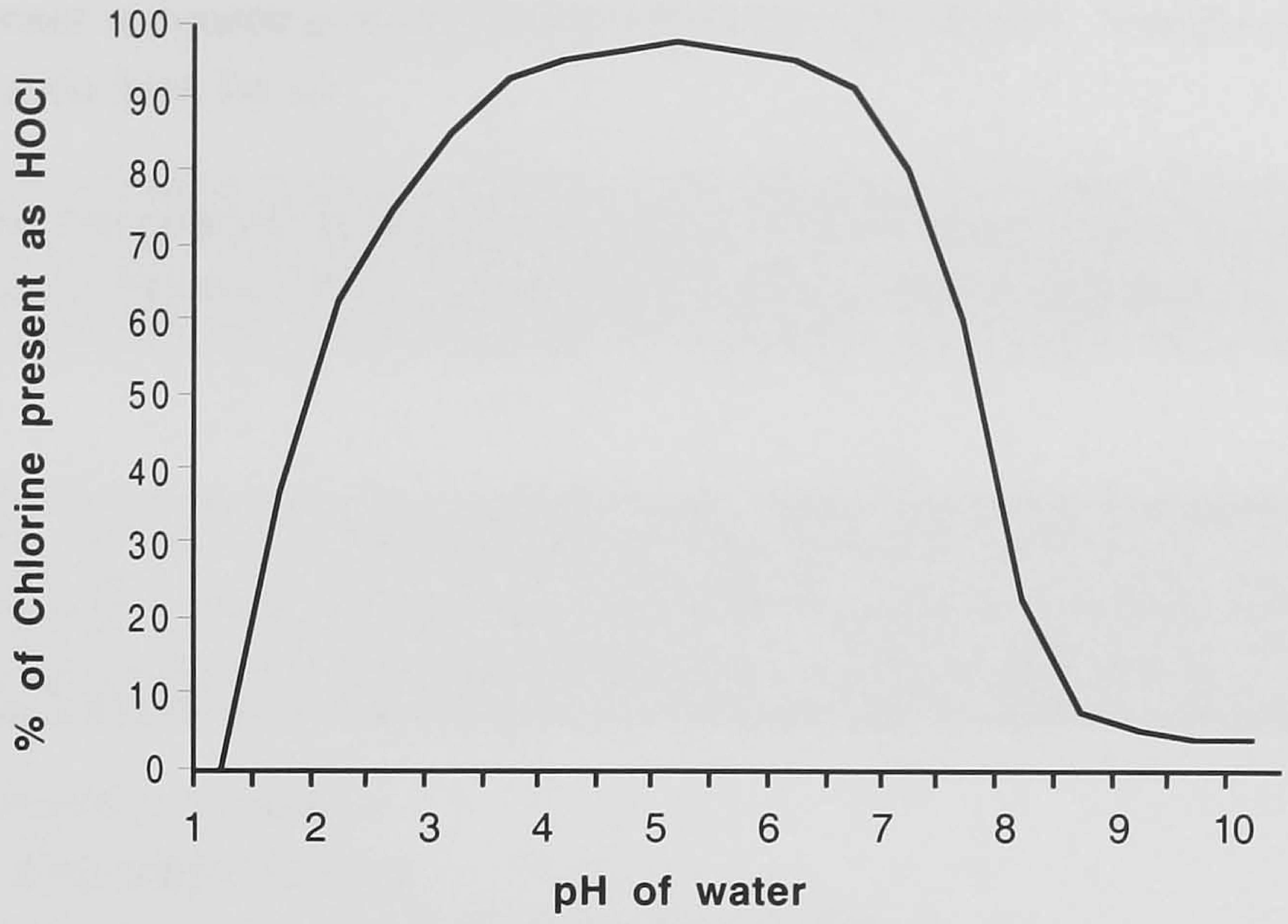
Hypochlorous acid solution [HOCl(aq)] is a most effective substance for killing bacteria.

Unfortunately, at lower pH values, HOCl reacts with any compound containing nitrogen to form various substances. These substances contain the N-Cl bond.

Examples of such compounds are: NCl_3 and $NHCl_2$. It is compounds like these that are causing the eye soreness.

At very high pH values, HOCl does not work to kill bacteria.

Now look at a graph given below.



As a group, discuss and answer the following questions:

(a) What pH is best for human bodies ?

(b) What pH is best to avoid nitrogen-chlorine compound formation ?

(c) Where do the nitrogen compounds come from ?

(d) Looking at the graph and information given at the top of this page, what pH is best to allow the HOCl to work to kill bacteria ?

(e) Look at your answers to (a), (b) and (d).

What pH would you recommend for the swimming pool water ?

(f) What has gone wrong that caused Helen, Paul and James to have sore eyes ?

Use this space for any notes, calculations, working etc

15

Trees and Cars

Your Name: ....

The following statement appeared in a well known American newspaper. It was concerned with ways to absorb carbon dioxide from the air.

"One tree can use up about 6 kg of carbon dioxide per year or enough to offset the pollution produced by driving one car for 42,000km."

Is this really true ?

You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

You are given the following information:

- Petrol is mainly octane [C_8H_{18}].
- An average small car gets about 10 km per litre of petrol.
- Octane weighs 700g per litre.

Is the quotation from the newspaper correct ?

(1) As a group, discuss how you might attempt to answer this question.

(2) Try the calculation yourselves (working as a group) - you will need a calculator.

Use this space for any notes, calculations, working etc

15

Trees and Cars (Revised)

Your Name: ....

The following statement appeared in a well known American newspaper. It was concerned with ways to absorb carbon dioxide from the air.

> "One tree can use up about 6 kg of carbon dioxide per year or enough to offset the pollution produced by driving one car for 42,000km."

Is the quotion from the newspaper correct?

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

You are given the following information:

- Petrol is mainly octane [C_8H_{18}].
- An average small car gets about 10 km per litre of petrol.
- Octane weighs 700g per litre.

(1) As a group, discuss how you might attempt to answer this question-write down a plan. If you are completely unusure what to do, *ask for a hint*.

(2) When you have a plan, if you find difficulty at any stage, *ask for a hint*.
Remember: you want to find out if one tree in one year can use up the carbon dioxide produced by an average small car in one year.

(2) You will need a calculator. Work as group, using rough calculations only.

Use this space for any notes, calculations, working etc

16

Bonding

Your Name: ....

The properties of a substance depend on its structure: the way its atoms, molecules or ions are arranged and held together.

The properties of compounds with different types of bonding are summarised below.

Type of Bonding	Melting Point	Boiling Point	Electrical Conductivity	Solubility in Water
Covalent	tend to be low occasionally very high	low or extremely high	poor	varies
Polar covalent	tend to be low	low or high	usually poor, some react with water to give conduction	usually soluble but some react
Ionic	high	very high	good - melted good - dissolved poor - as a solid	often soluble
Metallic	usually high	very high	very good	usually insoluble

You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Your problem is to work out a way to find out what type of bonding exists in aluminum chloride for which a possible formula might be: $AlCl_3$

As a group, you have £100 pounds to spend. You can spend less than £100 but you may not spend more !

You can pay for the results of various experiments.

Here is the price list:

(a)	measure melting point:	£30
(b)	measure boiling point:	£20
(c)	measure solubility:	£30
(d)	measure electrical conductivity as dissolved:	£30
(e)	measure electrical conductivity as melt:	£40
(f)	reaction with water:	£30

Discuss what results you want to buy. You can buy them altogether or you can buy them one at a time. Ask your teacher for the results that you choose. Now try to work out the type of bonding in aluminum chloride, writing dwon how you have worked out your answer.

Use this space for any notes, calculations, working etc

16

Bonding (Revised)

Your Name: ....

The properties of a substance depend on its structure: the way its atoms, molecules or ions are arranged and held together.

The properties of compounds with different types of bonding are summarised below.

Type of Bonding	Melting Point	Boiling Point	Electrical Conductivity	Solubility in Water
Covalent	tend to be low occasionally very high	low or extremely high	poor	varies
Polar covalent	tend to be low	low or high	usually poor, some react with water to give conduction	usually soluble but some react
Ionic	high	very high	good - melted good - dissolved poor - as a solid	often soluble
Metallic	usually high	very high	very good	usually insoluble

You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Your problem is to work out a way to find out what type of bonding exists in aluminum chloride for which a possible formula might be: $AlCl_3$

As a group, you have £100 pounds to spend to buy the results of various experiments. You can spend less than £100 but you may not spend more !

Here is the price list:

(a) measure melting point: £30
(b) measure boiling point: £20
(c) measure solubility: £30
(d) measure electrical conductivity as dissolved: £30
(e) measure electrical conductivity as melt: £40
(f) reaction with water: £30

(1) Discuss what results you want to buy to help you find out the type of bonding in aluminum chloride . You can buy them altogether or you can buy them one at a time. **Ask your teacher for the results that you choose**.

(2) Now try to work out the type of bonding in aluminum chloride, writing down how you have worked out your answer.

Use this space for any notes, calculations, working etc

17

Chemicals from Salt

Your Name: ....

There are endless supplies of salt (sodium chloride) in the sea. However, it is more useful to use rock salt, formed when ancient seas dried up. Useful chemicals are obtained from salt using electrolysis of salt solution in water, as electric current is passed through the salt solution.

The electrolysis of sodium chloride solution produces sodium hydroxide, chlorine and hydrogen. The overall equation is:

$$2NaCl \quad + \quad 2H_2O \xrightarrow{\text{electrolysis}} Cl_2\,(g) \quad + \quad 2NaOH\,(aq) \quad + \quad H_2\,(g)$$

These three products are widely used in many important industries.

During the electrolysis process, the products must not be allowed to mix. Three types of electrolysis cells are used in industry. The table below summarises the main features of three cells, known as the membrane cell, the diaphragm cell and the mercury cell.

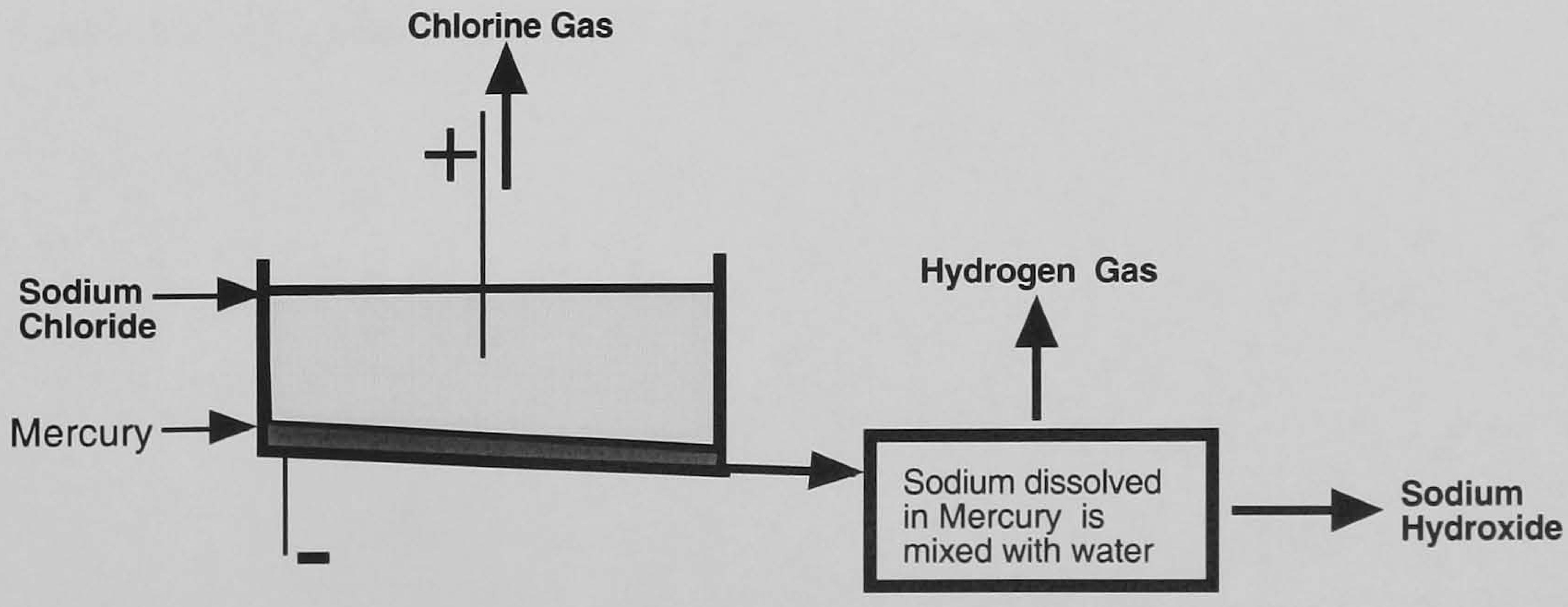
	Membrane	Diaphragm	Mercury
Concentration of NaOH formed	30-35%	11-12%	50%
Contamination of NaOH by NaCl	0.05 g / l	10 g / l	0.03 g / l
Environmental problems	no	asbestos can cause lung cancer	mercury vapor is poisonous
Electricity used (kWh) per tonne NaOH	2200	2500	3100
Special features	needs very pure brine	diaphragms must be replaced frequently	mercury is very expensive but little is wasted

In all three cells, chloride ions (Cl^-) move to the **anode** where they give up electrons to become chlorine gas:

$$2Cl^- \longrightarrow Cl_2\,(g) \quad + \quad 2e^-$$

The Mercury cell

The Mercury enters this vessel at the bottom and acts as the cathode (-). The sodium is released at the cathode and it dissolves in the mercury. The sodium-mercury mixture reacts with water to form sodium hydroxide and the mercury is pumped back continuously to be the cathode.



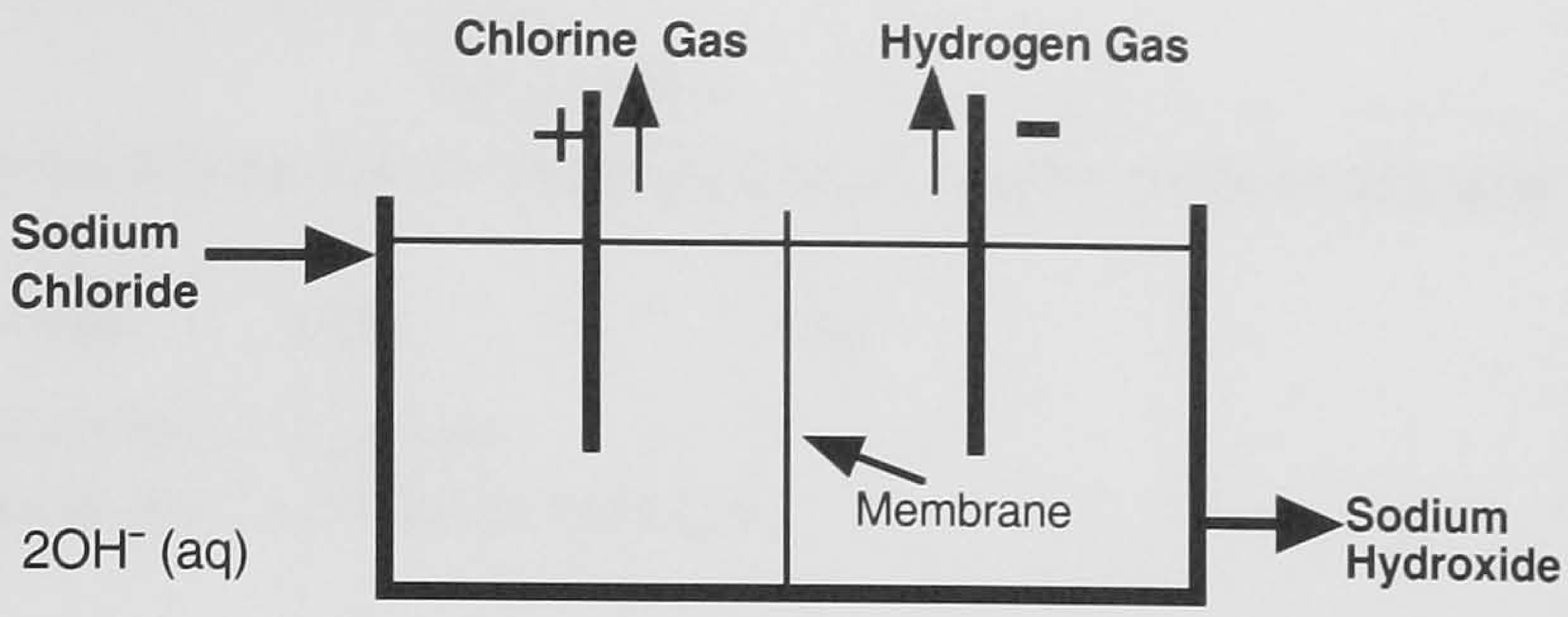
$$\underset{\text{dissolved in mercury}}{2Na} \quad + \quad 2H_2O \longrightarrow 2NaOH \quad + \quad H_2$$

The Membrane cell

The membrane is designed so that only sodium ions can pass through.

Hydrogen gas and hydroxide ions (OH^-) are formed at the **cathode**:

$$2H_2O + 2e^- \longrightarrow H_2\,(g) + 2OH^-\,(aq)$$

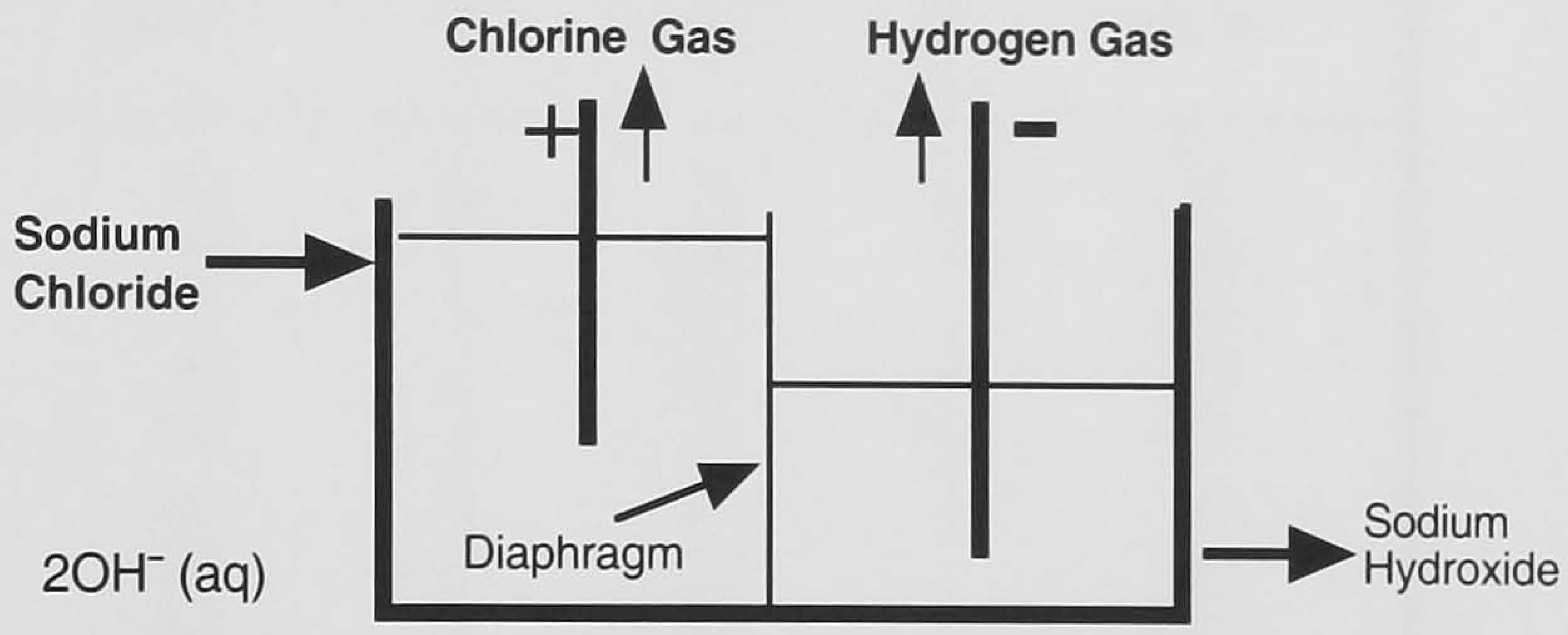


The Diaphragm cell

The diaphragm is a sheet of gauze coated with asbestos which allows liquid to pass through.

Hydrogen gas and hydroxide ions (OH^-) are formed at the **cathode**:

$$2H_2O + 2e^- \longrightarrow H_2\,(g) + 2OH^-\,(aq)$$



You will be working in a small group.
Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

Before you start answer the questions below, work as a group and discuss each cell in turn. The cells are quite complicated. Look at the diagrams and the equations and try to work out how each cell actually works.

Now try discussing the following:

(1) Why do you think that the cell products are not allowed to mix during the process ? Think what might happen if any two of the products were allowed to mix. Discuss with your group and write down your answers.

(2) Still working as a group, write down the strengths and weaknesses for each cell as a way to make the three products. Can you see any problems besides the problems that have been mentioned? Write down your answers.

(3) Imagine that you are running a company making these three products from salt. Your company is thinking about building a new factory. Which process do you prefer to choose ? Write down your choice and give **two reasons** why you are making that choice.

Use this space for any notes, calculations, working etc

18

Rates of Reaction

Your Name: ....

A group of students were investigating some of the factors that influence the rate of reaction between zinc and dilute hydrochloride acid:

$$Zn \quad + \quad 2HCl \longrightarrow ZnCl_2 \quad + \quad H_2$$

They carried out four experiments. In each case, all the zinc reacted.
They collected and recorded the amount of hydrogen gas produced every minute.
Their results are shown in the table below.

Time (mins)	Volume of Hydrogen (cm^3)			
	expt 1	expt 2	expt 3	expt 4
1	25	20	60	15
2	50	40	120	30
3	75	65	150	45
4	100	75	165	60
5	125	85	175	75
6	145	90	180	90
7	160	90	180	105
8	170	90	180	120
9	175	90	180	135
10	180	90	180	145
11	180	90	180	155
12	180	90	180	165
13	180	90	180	175
14	180	90	180	180
15	180	90	180	180

You are working in a small group of three. You will need to plot the results from the four experiments in order to be able to discuss what they mean. Share out the work as follows, checking with each other that you are plotting the graphs in the same way:

Person 1 — Plot time against volume of hydrogen in experiment 1 and plot time against volume of hydrogen in experiment 2, both graphs on the same graph paper provided.

Person 2 — Plot time against volume of hydrogen in experiment 1 and plot time against volume of hydrogen in experiment 3, both graphs on the same graph paper provided.

Person 3 — Plot time against volume of hydrogen in experiment 1 and plot time against volume of hydrogen in experiment 4, both graphs on the same graph paper provided.

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

The first experiment used 1g zinc powder and 1M (1 mole per litre) hydrochloric acid at 20°C.

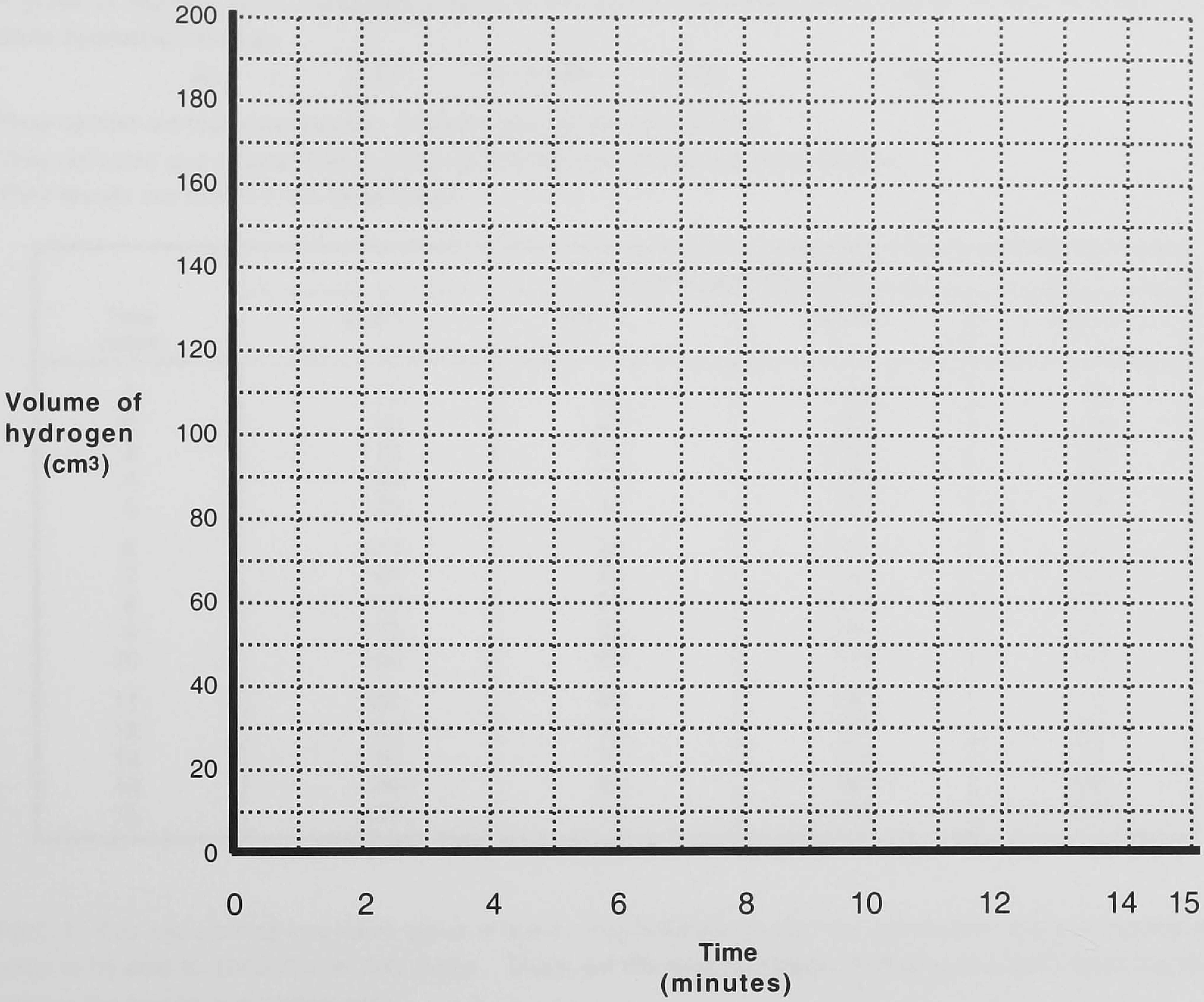
Look at each of the graphs together and discuss answers to the following:

(1) Look at the graph showing experiment 1 and experiment 2. Work out what might have changed to give the graph from experiment 2. Write down your agreed answers.

(2) Look at the graph showing experiment 1 and experiment 3. Work out what might have changed to give the graph from experiment 3. Write down your agreed answers.

(3) Look at the graph showing experiment 1 and experiment 4. Work out what might have changed to give the graph from experiment 4. Write down your agreed answers.

Rates of Reaction



Use this space for any notes, calculations, working etc

18

Rates of Reaction (Revised)

Your Name: ....

A group of students were investigating some of the factors that influence the rate of reaction between zinc and dilute hydrochloride acid:

$$Zn + 2HCl \longrightarrow ZnCl_2 + H_2$$

They carried out four experiments. In each case, all the zinc reacted.
They collected and recorded the amount of hydrogen gas produced every minute.
Their results are shown in the table below.

Time (mins)	Volume of Hydrogen (cm^3)			
	expt 1	expt 2	expt 3	expt 4
1	25	20	60	15
2	50	40	120	30
3	75	65	150	45
4	100	75	165	60
5	125	85	175	75
6	145	90	180	90
7	160	90	180	105
8	170	90	180	120
9	175	90	180	135
10	180	90	180	145
11	180	90	180	155
12	180	90	180	165
13	180	90	180	175
14	180	90	180	180
15	180	90	180	180

Part 1 You are working in a small group of three. You will need to plot the results from the four experiments in order to be able to discuss what they mean. Share out the work as follows, checking with each other that you are plotting the graphs in the same way:

Person 1 — Plot time against volume of hydrogen in experiment 1 and plot time against volume of hydrogen in experiment 2, both graphs on the same graph paper provided.

Person 2 — Plot time against volume of hydrogen in experiment 1 and plot time against volume of hydrogen in experiment 3, both graphs on the same graph paper provided.

Person 3 — Plot time against volume of hydrogen in experiment 1 and plot time against volume of hydrogen in experiment 4, both graphs on the same graph paper provided.

> You will be working in a small group.
> Discuss the possible answers to the questions below and one member of the group can write in your agreed answers on to the "Answer Sheet".

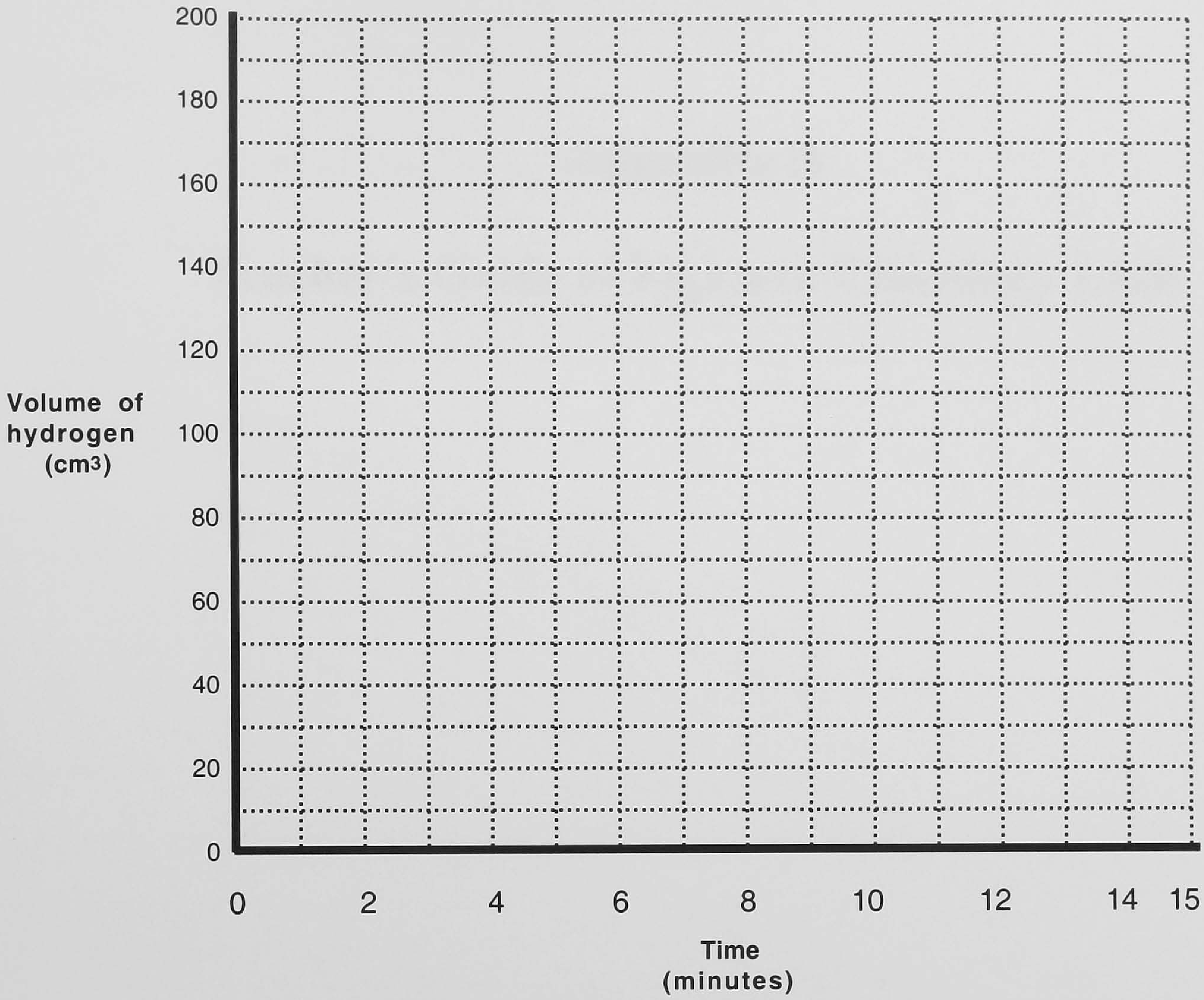
Part 2 The first experiment used 1g zinc powder and had a concentration of hydrochloric acid (40 gram per liter) at 20°C. Look at each of the graphs together and discuss answers to the following:

(1) Look at the graph showing experiment 1 and experiment 2. Work out what might have changed to give the graph from experiment 2. Write down your agreed answers.

(2) Look at the graph showing experiment 1 and experiment 3. Work out what might have changed to give the graph from experiment 3. Write down your agreed answers.

(3) Look at the graph showing experiment 1 and experiment 4. Work out what might have changed to give the graph from experiment 4. Write down your agreed answers.

Rates of Reaction



Use this space for any notes, calculations, working etc

Appendix B

Teacher's Guide of Eighteen Chemistry Units

Chemproblem Number 1

Argon and Electric Welding

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 3 Atoms and the Periodic Table	• Key properties of Noble Gases

Learning Outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Begin to develop critical skills in relation to chemistry
- Be able to correct the errors of a report in newspaper.
- Become more aware of safety issues related to chemistry.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "Argon and Electric Welding" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 15-20 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible Conclusions and Answers

Pupils should be aware that argon does not burn and does not support combustion. Therefore, it cannot use up oxygen. Pupils may not be aware of the nature of electric welding in which the electrical discharge generates the heat to melt the metal. Electric welding does not involve oxygen and the reason for using argon is to keep oxygen (from the air) away from very hot metal and reduce possibilities of metal oxidation.

Chemproblem Number 2

Which is the Best Fuel ?

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 5 Fuels • Balancing equations	• Know that a fuel is a chemical which burns giving out energy • Be aware that combustion is a reaction of a substance with oxygen

Learning Outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Gain practice in writing balanced equations for combustion reactions.
- Gain practice in calculating and using formula masses.
- Become more aware of the use of rough calculations in taking decisions.
- Become more able to justify if an assumption is reasonable.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "Which is the Best Fuel ?" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 30-35 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible conclusions and answers

Part 1: The combustion equations are:

$$C + O_2 \longrightarrow CO_2$$

$$C_{11}H_{24} + 17O_2 \longrightarrow 11CO_2 + 12H_2O$$

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

Parts 2 and 3: Pupils are not expected to carry out the rough calculations using the concept of the mole although they may choose to do so. However, the mole is a notoriously difficult concept and need not be invoked. They can quickly estimate the number of formula masses of each in 1000g of each and hence work out the relative number of molecules formed in each equation. This shows that the methane gives the greatest number of product molecules and is, on the assumption given, likely to provide the most energy for each 1000g burned.

The approximate answers that pupils may reach are given overleaf.

	Formula Mass	Number of formula masses in 1000g		'Molecules' formed
Carbon	12	83	—— x 1 ——►	83
$C_{11}H_{24}$	156	6.4	—— x 23 ——►	147
CH_4	16	62.5	—— x 3 ——►	188

To show how this works, consider methane.

With a formula mass of 16, there are 1000 ÷16 [= 62.5] formula masses [moles] in 1000g.

The equation gives three product molecules.
Therefore, there are 3 x 62.5 [= 188] 'equation molecules' [moles of product molecules] formed.

Because comparisons only are being made, this is sufficient.

The purpose of the exercise is to allow the pupils to work with the data to reach an answer and then be able to justify why they think their answer is valid.

Part 4: Pupils may see that they are assuming that the formation of H_2O and CO_2 produces similar energy. At this stage, they will not be aware of ideas like bond energy. They will not aware that the overall energy changes depend on bonds broken in reactants and bonds made in products. However, in discussion, they may be able to begin to share ideas that lead towards these ideas, using their own language.

In summary, they may be able to see that, if the various bonds are similar in energy then the energy released is approximately proportional to the number of molecules formed. In fact, the assumption is good enough to show that methane will release most energy.

Chemproblem Number 3

The Chewing Gum Problem

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 15 Carbohydrates and related substances	• Hydrolysis of carbohydrates

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Apply the ideas of hydrolysis of carbohydrates.
- Gain experience in searching for information that they need to reach an answer.
- Gain experience in weighing the significance of evidence.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "The Chewing Gum Problem" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 25 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible conclusions

Pupils can approach the problem in at least two ways. In one approach, they may consider setting up a long term experiment with large numbers of people, half of whom use sugar free chewing gum and half using ordinary gum. Using appropriate controls to match the two groups, they could seek to study the long term effects on teeth decay.

However, the more likely approach is to gather chemical evidence about what is happening in the mouth during gum chewing and seek to understand the chemistry of totth decay and the effects of the two types of gum on this. The chemical evidence is provided overleaf as background information for yourself.

Summary

(1) The ordinary gum contains carbohydrates such as starch or sucrose, but the sugar-free gum has no carbohydrates in it, it just contains sugar substitutes such as Xylitol or Sorbitol.

(2) The breakdown of starch or sucrose to monosaccharides is called hydrolysis.
The hydrolysis of sucrose is:

$$\text{sucrose} \quad + \quad \text{water} \quad \longrightarrow \quad \text{glucose} \quad + \quad \text{fructose}$$

$$C_{12}H_{22}O_{11} \quad + \quad H_2O \quad \longrightarrow \quad C_6H_{12}O_6 \quad + \quad C_6H_{12}O_6$$

(3) To answer the question, various pieces of information may be needed:

- **What is tooth enamel?**
  Tooth enamel is composed of 95% mineral calcium hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$.

- **What is tooth decay?**
  Tooth decay is caused when tooth enamel is demineralised by acid in the mouth:
  During acid attack, hydroxyapatite dissolves, releasing calcium ions and hydrogenphosphate ions into the saliva:

  $$Ca_{10}(PO_4)_6(OH)_2 \quad + \quad 8H^+ \quad \longrightarrow \quad 10\,Ca^{2+} \quad + \quad 6HPO_4^{2-} \quad + \quad 2H_2O$$

- **What are the acids?**
  The acids involved are lactic acid, acetic acid and propanoic acid. They are formed in the mouth when bacteria attack and break down carbohydrates like glucose and fructose, released from the hydrolysis of sucrose. The pH in the mouth falls dramatically after sugar has been eaten, then, after about one hour, rises back to pH 7.

  After eating, the pH of the mouth, which is normally pH 6.5, falls rapidly to pH 4.5 because bacteria in the plaque produce high concentration of acids.

- **What is sugar substitutes?**
  Sugar substitutes such as xylitol and sorbitol are broken down by bacteria to form acids at a much slower rate than sucrose. Xylitol also has an antibacterial effect.

- **How does the saliva work with chewing gum?**
  Saliva contains hydrogencarbonate (bicarbonate) ions and antibacterial agents such as fluoride ions. It helps to protect against microbial activity in the mouth by inhibiting the ability of bacteria to break down carbohydrates and generate acids.

  Chewing gum can stimulate saliva flow by up to 10 times its normal rate. The stimulation leads to a change increases the bicarbonate concentration, raising the pH and enhancing the saliva's ability to neutralise plaque acid. It also causes an availability of calcium and phosphate ions, which can help heal a tooth's surface in the early stage of tooth decay.

(4) Although the pupils are not expected to obtain an answer, the conclusion is that chewing sugar-free gum can help in the fight against tooth decay. The pupils are expected to be able to devise a strategy to obtain an answer.

Chemproblem Number 4

Fluoride Improves Tooth Decay ?

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 3 Atoms and the periodic table	• Naming of compounds

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be able to spot chemical errors in a newspaper report
- Begin to seek valid chemical explanations for observed data.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "Fluoride Improves Tooth Decay" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 15-20 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible Errors

Fluoride strengthens teeth by bonding with calcium to form calcium fluoride....
Fluorine is the element, fluoride is already bonded to something.

Calcium fluoride is a harder, denser material than calcium alone,...
Calcium, as an element, is not present in teeth - pupils may remember that the metal reacts with water. However, the fluorine can bond with calcium to form calcium fluoride.

Calcium is the main ingredient in enamel...
This leaves the impression that, in some way, calcium is mixed with other materials to form tooth enamel. Calcium is bonded to the other elements.

Extra Information: In fact, fluoride does help reduce tooth decay: the fluoride ion replaces the hydroxide ion in tooth enamel, changing hydroxyapatite $Ca_3(PO_4)_6(OH)_2$ to fluorapatite $Ca_3(PO_4)_6F_2$. Under acid conditions in the mouth, the fluorapatite is less soluble than hydroxyapatite and more resistant to the bacteria. Strictly, according to the molecule formula $Ca_3(PO_4)_6(OH)_2$, the most abundant element in tooth enamel is not calcium but oxygen !

Chemproblem Number 5

Glowing Splint Problem

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 5 Fuels • Air pollution	• Composition of the air • Basic idea of a catalyst

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be able to explain the formation of nitrogen dioxide gas in a car engine.
- Be more aware of the pollution problems related to nitrogen dioxide and how these are reduced.
- Be able to suggest possible explanations for an experiental observation.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "The Glowing Splint Problem" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 20-25 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible conclusions and methods

In part 1, pupils are being encouraged to think again through what is happening in the combustion of fuels. In a car cylinder, burning fossil fuels at high temperatures provides the condition for nitrogen and oxygen that are from the air to form nitrogen oxides, nitric oxide initially which then is converted rapidly into nitrogen dioxide.

Nitrogen dioxide gas can combine with water to form nitric acid, which can condense in the exhaust system and cause corrosion. Equally, nitrogen dioxide can emerge into the atmosphere to form acid droplets and to react with other pollutants. The oxide and its products are all harmful to the environment and to humans.

There are two ways to reduce the problem of NO_2 in a car: transition metal catalysts can convert the nitrogen dioxide back to nitrogen and oxygen or the fuel to air ratio can be improved to lower to formation of oxides of nitrogen. Neither is perfect in that the catalysts work poorly at low temperatures (when a car starts) and the formation of the oxides can be eliminated completely by engine adjustment.

In part 2, using the hint of the idea of catalysis, pupils are asked to explain what appears to be quite illogical: the nitrogen dioxide oxygen mixture would not be expected to re-kindle the glowing splint by comparison with air. In fact, a glowing splint catalyses the decompose of NO_2 to N_2 and O_2. Pupils, in their discussion, may come up with other possible explanations eg. carbon is more reactive than nitrogen and is displacing the nitrogen from the dioxide, releasing the oxygen - perfectly reasonable.

Chemproblem Number 6

Heat Packs for Mountaineers

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 11 Metals	• Oxidation • The reactivity of metals

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be willing to speculate to develop explanations based on previous knowledge.
- Become more able spotting hidden but relevant information to solve problems.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "Heat Packs for Mountaineers" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 25-30 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible answers

The most difficult step is for pupils to see that it is oxygen from the air coming into the porous fabric bag once the sealed outer plastic bag is opened.

(1) When the protective plastic bag is removed, the powdered iron will react with the O_2 in air to produce Iron (II) oxide. The energy comes from the oxidation of iron.

(2) According to the reactivity of metals, we cannot use active metals like sodium or potassium because of violent reaction. The highly unreactive metals like copper or silver are also not suitable for the Heat Packs because of slow reactions. Therefore, a moderately reactive metal like iron is rather suitable. Alternatives must have comparable reactivity (and not be too expensive); possibles: zinc is a bit too reactive, tin too slow, nickel too expensive, manganese might work.

Chemproblem Number 7

How Can We Obtain Iron?

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 11 Metals	• Chemical equations

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be aware how iron is obtained from iron ores.
- Gain practice in interpreting chemical equations.
- Be able to select and re-arrange the equations reasonably.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled How Can We Obtain Iron? to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 25-30 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible answers

(1) All three are possible. % iron, byproducts (like SO_2), location of factory are all factors.

(2) The reasonable processes of converting iron into iron metal are, if haematitie is used:

Equations 1 plus 3 or equation 2	Production of carbon monoxide
Equation 9 plus 10	Reduction of iron oxides with carbon monoxide
Equation 4 plus 5	Removal of impurities.

If Magnetite is used, equation 8 replaces equation 9 while, if pyrities is used, equation 7 has to be carried out in advance - the sulphur dioxide cannot be vented to the air with the other waste gases and causes considerable destruction to the actual furnace.

(3) Waste gases are largely nitrogen (60%), carbon monoxide (30%) and carbon dioxide (10%). If pyrites is used, there is also sulphur dioxide. Sulphur dioxide (highly toxic and corrosive) and carbon monoxide (highly poisonous) and carbon dioxide (greenhouse gas) all pose problems.

Chemproblem Number 8

Moving Gases

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• The properties of gases	• Formula masses

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be able to draw conclusions such as a graph or a brief principle from given data.
- Be able to design an appropriate method to check if the conclusion is correct.
- Develop the ability of prediction.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "Moving Gases" to each <u>pupil</u>.
Give one copy of the blue Answer sheet to each <u>group</u>.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

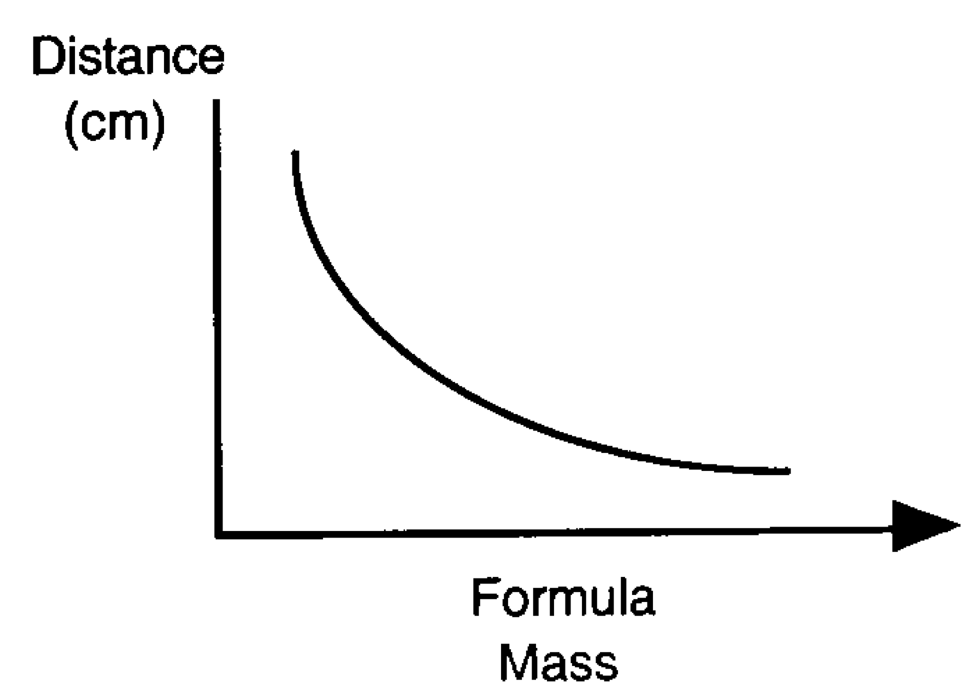
(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 20-25 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible conclusions and prediction



(1) Pupils may play with several ideas before they begin to spot that the distance travelled is related to molecular mass. They may simply see that the larger the formula mass, the smaller the distance. This is sufficient to make an estimate of the answer. However, some may think of drawing a rough graph, as shown alongside.

Others may go further: if they look at sulphur dioxide and methane, they may see that quadrupling the mass halves the distance travelled. Some may then see the inverse square relationship.

(2) Whatever they do, they can test their idea by looking at other gases in the table to see if their hypothesis stands up.

(3) Their answer for chlorine will depend how which method they used. The most accurate answer, from the data given, is 48 cm.

Chemproblem Number 9

The Ozone Problem

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• The gaseous state • Topic 4 How atoms combine.	• Chemical formula

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be able to spot patterns from given experimental information
- Be able to draw inferences from the given information.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "The Ozone Problem" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 25-30 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible conclusions and methods

Part 1 Pupils will struggle for a little while before they begin to see that it is the number of gas molecules that is related to the gas valume: Gas volumes are related to balanced equations. They then test this out in reactions (1) and (2).

(1) The volume of CH_2O is 10 ml.
(2) The volume of CO_2 is 20 ml.

Part 2 In accordance with the rule they have established, there must be two molecules of ozone giving three molecules of oxygen:

$$2(\text{Ozone}) \longrightarrow 3O_2$$

This gives 6 oxygen atoms on the right, demanding six on the left: O_3 is the only possible way to achieve this.

Chemproblem Number 10

The Phosphorus Problem

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry .

Curriculum links	Prior knowledge
• Separate of mixtures (pre-Standard Grade)	• Separate mixtures by taking advantage of the different physical and chemical properties.

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Gain experience in assessing data
- Be able to draw inferences from the given information.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "The Phosphorus Problem" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 20-25 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible conclusions and methods

Pupils will find it difficult at the start to sort through the amount of data to see what is significant and useful. Looking at melting and boiling points shows clearly that, with very slight cooling, the calcium silicate solidifies leaving the others as gases. In practice, liquid calcium silicate is run out of the bottom of the furnace, the three gases emerging in a pipe from the top.

If the gases are merely cooled to around 25°C, the phosphorus will solidify, leaving carbon monoxide and silicon tetrafluoride as gases. However, there is no way to get at the phosphorus without letting in air, thus causing a major fire.

The three gases have to be cooled in water. The problem here is that the silicon tetrafluoride reacts to form silicon dioxide which then contaminates the phosphorus.

The trick is to cool in water at a temperature above 44°C (in fact about 70°C us used). At this temperature, the phosphorus stays as a liquid and can be separated readily from the solid silicon dioxide. After the silicon dioxide is removed, the water is allowed to cool and the solid phosphorus forms under the water. The carbon monoxide continues on as a gas. The water will, in fact, contain dissolved hydrogen fluoride but this does not contaminate the solid phosphorus.

Chemproblem Number 11

The Leaking Pipe

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 5 Fuels	• The fractional distillation of crude oil

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be able to distinguish the difference between the LP gas and the Natural gas.
- Be able to judge the accuracy of a report and recognise errors.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "The Leaking Pipe" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 15-20 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible Errors

The spokeswoman confuses LP gas with Natural gas. Propane gas arises from oil refining (along with methane, ethane etc). Propane can be liquified readily and transported under pressure as a liquid. It will evaporate when the pressure drops, not necessarily when it comes in contact with air.

Natural gas is, of course, mainly methane. This can also be liquified under pressure for transportation and, on reduction of the pressure, will evaporate.

In fact, natural gas liquids is a confusing description.

Chemproblem Number 12

Salt, Salts and pH

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 9 Reactions of Acids.	• The pH scale as a measure of acidity and alkalinity.

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Gain experience in drawing conclusions from data.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "Salt, Salts, and pH" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 20-25 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible Conclusions

(1) Solutions of salts in water are not always neutral.

(2) Solutions of salts of transition metals are acidic.

(3) Solutions of carbonates are basic (pH more than 7).

(4) Solutions of salts containing group 1 metals such as sodium always have a pH of 7 or more.

(5) Solutions of salts contains anions such as Cl^-, NO_3^-, SO_4^{2-} always have a pH of 7 or less.

Chemproblem Number 13

Solubility

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Gradechemistry.

Curriculum links	Prior knowledge
• Topic 9 Reactions of acids • Topic 7 Properties of substances	• Solubility, precipitation

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be able to draw conclusions from data.
- Develop the ability of prediction by using data provided.
- Sift data intelligently to design an appropriate method to separate the mixture of solutions.
- Be able to predict the result of mixing two solutions.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "Solubility" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 30-35 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible conclusions and approaches

(1) Solubility rules that they might deduce from the data given:

- Any solid is soluble if it contains sodium, potassium and nitrate ions.
- Most of the chlorides are soluble(only lead and silver chlorides are insoluble).
- Some of the sulphates are soluble(calcium, barium, lead and silver sulphates are insoluble).
- Any solid is insoluble if it contains hydroxide ions and carbonate ions except for sodium and potassium compounds.
- Most lead compounds are insoluble except lead nitrate.

(2) Magnesium hydroxide will be formed.

(3) Add a solution which contains negative ions such as CO_3^{2-}, SO_4^{2-}, OH^-, F^-, Cl^- (except NO_3^-) to the mixture solution of lead nitrate and sodium nitrate. The lead ions will combine with these negative ions to form precipitates. Filter the precipitates off, rest of the solution is sodium nitrate. Care must be taken not to add excess, thus contaminating the sodium nitrate.

(4) 0.16 < $Sr(OH)_2$ > 14 and 0.0002 < $SrSO_4$ > 0.2
In fact, the solubility of strontium hydroxide is 11.7g per 100g, the solubility of strontium sulphate is 0.0006g per 100g.

Chemproblem Number 14

The Swimming Pool Problem

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Gradechemistry.

Curriculum links	Prior knowledge
• Topic 8 Acids and Alkalis	• Concept of pH • Acidic solutions contain H

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be able to write down the ionisation equations.
- Be able to sift information and draw conclusions.
- Bring information together to judge the best pH value of water for the swimming pool.
- Begin to see the significance of chemistry in a leisure activity.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "The Swimming Pool Problem" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 30-35 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible conclusions

Part 1 The desirable properties for swimming pool water might be: clear water, no bacteria, no nasty smells, clean pool walls and surrounds are, warm, reasonable pH (they may suggest 5.5 to match many shampoos and soaps)

Part 2 They will be unsure of the ionisation of hypochlorous acid:

$$HOCl(aq) \longrightarrow H^+(aq) + OCl^-(aq)$$

Part 3 Referring to the information and the graph, the answers are:

(a) The good pH value for swimmers could be anything between 5.5 and 7.
(b) Nitrogen-chlorine compound formation happens at lower pH values.
The pH must be kept above 6.
(c) The best pH value to allow the HOCl to kill bacteria is less than 8, say.
(d) pH 6 - 8.
(e) They had sore eyes might due to the pH value decreasing below 6.

Chemproblem Number 15

Trees and Cars

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 6: structures and reactions of hydrocarbons • Topic 5 Fuels	• Formula Masses

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be able to write and balance the combustion equation of octane.
- Be able to carry out some chemical arithmetic.
- Be aware that the role of trees is important in reducing the CO_2 in the environment.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "Trees and Cars" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 30-35 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible calculation

There are several ways to tackle the problem. Here is a possible route.

A balanced equation: $2\,C_8H_{18} + 25\,O_2 \longrightarrow 16\,CO_2 + 18\,H_2O$

From this (or by simply deducing that there are 8 carbons per molecule of octane),
114g of octane will give rise to 352 g of carbon dioxide.

1 litre octane has a mass of 700 g. Thus,

Mass of CO_2 from 1 litre = $(700 \div 114) \times 352$ g = 2161g

The car will use 4200 litres of petrol.

The CO_2 produced will weigh: 2151 x 4200 g = 9 076 000 g = 9076 Kg [= > 9 tonnes]

Thus, the number of trees required to absorb the CO_2 in a year is over 1500 !!
The newspaper report is completely incorrect.

Chemproblem Number 16

Bonding

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 7 Properties of substance	• The types of bonding including covalent, polar covalent, ionic and metallic.

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Learn how to assess the value of inforamtion gained experimentally
- Be able to select an appropriate method to obtain an answer.
- Develop the ability of sifting information.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "Bonding" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 15-20 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible conclusions

The information to be given to pupils is:

Melting point:	Does not melt, sublimes at 193°C.
Boiling point:	Sublimes.
Solubility in water:	Extremely soluble.
Electrical conductivity as dissolved:	Solution conducts very well.
Electrical conductivity as melt:	Does not melt.
React with water:	Disssolves rapidly, sometimes with a sight "fizz".

The bonding in aluminium chloride is polar covalent, in all phases. The compound tends to exist as a dimeric molecules Al_2Cl_6. In water, there is rapid dissolving, sometimes with a reaction giving a slight "fizz" as the chloride is hydrolysed to give free hydrated aluminium ions and chloride ions. In this phase, the bonding is ionic. Thus, aluminium chloride is a polar molecule but, on reaction with the water, ions are set free.

Chemproblem Number 17

Chemicals from salt

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 7 Properties of substances	• Electrolysis

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be able to predict what might happen from the given relevant information.
- Develop the abilities of discrimination between three electrolysis methods.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "The Chemicals from Salt" to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 25-30 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible conclusions

The pupils will not have met the reactions between the various products but might be able to deduce or guess some of the reactions:

(a) Hydrogen and chlorine are likely to react to form hydrogen chloride.
(b) Chlorine, being a nonmetalic element is likely to react with sodium hydroxide (an alkali).
They will not have met hypochlorite as a possible product.
(c) Hydrogen and sodium hydroxide do not react but they probably could not deduce this.

The strengths and weaknesses for each cell are shown below:

	Strengths	Weaknesses
Membrane	uses the least energy high purity and concentration of NaOH no environmental problems	needs very pure brine
Diaphragm	uses low energy	low purity and concentration of NaOH asbestos can cause serious disease replace diaphragms frequently
Mercury	highest purity and concentration of NaOH	use the most energy mercury vapour is poisonous mercury is expensive

The mercury cell still dominates the market and works extremely well. The poisonous nature of mercury (small amounts escape into the marine environment) is the main problem. The diaphragm cell started to replace mercury cells but, latterly, with the development of membrance technology, the membrance cell is the preferred option.

Chemproblem Number 18

Rates of Reaction

Teacher's Guide

Introduction

The unit is written for 14-15 years old pupils following Standard Grade chemistry.

Curriculum links	Prior knowledge
• Topic 1 Chemical reaction • Topic 2 Speed of reactions	• Reaction of acids with metal to produce gas

Learning outcomes

Pupils are being asked to work in a small group to try to solve problems and should develop skills in working as a team. In addition, pupils should:

- Be able to plot graphs of the results from the experiments.
- Be able to find out the factors, which influence the speed of a chemical reaction.
- Gain more experience in communicating and cooperating with each other.

Guidelines

(1) Form the class into groups of 3, with an occasional group of 4 to balance numbers.

(2) Give a copy of the unit entitled "Rates of Reaction" and the graph paper provided to each pupil.
Give one copy of the blue Answer sheet to each group.
Pupils will take a few minutes to read the unit before group discussion starts.
Have scrap paper available if requested.

(3) Allow enough time for the groups to discuss and agree answers to the questions.
Do not take part in the group discussions unless pupils get completely confused.

(4) When pupils have finished, give each pupil a copy of the yellow sheet entitled "Endpiece".
Allow a few minutes for them to complete this on an individual basis.

(5) At the end, collect in all the sheets used for return to the Centre for Science Education.
A suggested time for the unit is about 30-35 minutes.

(6) You may wish to lead an open class discussion for a few minutes at the end.
This time can be used to comment on the problem and to summarise conclusions.

Possible answers

(1) Experiment 2 involved 0.5g of zinc.

(2) Experiment 3 might have happened for any (or a combination) of the following reasons:
- Temperature more than 20°C,
- A catalyst was used.
- The concentration of the acid than 1 M was increased.

(3) Experiment 4 might have happened for any (or a combination) of the following reasons:
- The concentration of acid was less than 1M.
- The zinc was in larger lumps (not powdered)
- The temperature was reduced to less than 20°C.

Appendix C

The Exemplary Answer Sheets

1

Answer Sheet

Argon and Electric Welding

Please write your names here:

....

....

After discussing with your group, write down the conclusions you think that you can make.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

If you need more space, use the other side

14

Answer Sheet

The Swimming Pool Problem

Please write your names here:

....

....

After discussing with your group, write down the conclusions you think that you can make.

Part 1 ....

....

....

Part 2 ....

....

....

....

....

....

Part 3 ....

....

....

....

....

If you need more space, use the other side

Appendix D

Evaluation Sheets (Three Versions)

Endpiece

Now work on your own. Think about the problem you have just tried to solve.
Answer the following questions to show how you tackled the problem.

Please write your name here: ....

Tick the box that best describes your experience in tackling this problem.	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree
The problem was enjoyable.	☐	☐	☐	☐	☐
The problem was difficult.	☐	☐	☐	☐	☐
I found that solving this problem was satisfying.	☐	☐	☐	☐	☐
The problem was completely new to me.	☐	☐	☐	☐	☐
I learned nothing from the problem.	☐	☐	☐	☐	☐
I had enough previous knowledge to solve the problem.	☐	☐	☐	☐	☐
I prefer solving problems on my own.	☐	☐	☐	☐	☐
We worked well together as a group.	☐	☐	☐	☐	☐
We did not share the work out evenly in our group.	☐	☐	☐	☐	☐
I found the group discussion helpful.	☐	☐	☐	☐	☐
At the end, we were not sure we had the correct answer.	☐	☐	☐	☐	☐
I could not have solved the problem by myself.	☐	☐	☐	☐	☐
I needed the other group members to help me remember background information	☐	☐	☐	☐	☐

Please answer the following questions.

What did you do first to solve the problem ? ....

....

What was the second step ? ....

....

What did you need to know before you began ? ....

....

What was the easiest part in the problem ? ....

....

What was a hindrance in preventing you from reaching a solution ?..

....

How did you overcome obstacles in the problem ? ....

....

In what ways did working in a group help to solve the problem ? ....

....

What have you learned from the problem ?...

....

Endpiece

Now work on your own. Think about the problem you have just tried to solve. Answer the following questions to show how you tackled the problem.

Please write your name here: ....

Tick the box that best describes your experience in tackling this problem.

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree
The problem was enjoyable.	☐	☐	☐	☐	☐
The problem was difficult.	☐	☐	☐	☐	☐
I found that solving this problem was satisfying.	☐	☐	☐	☐	☐
The problem was completely new to me.	☐	☐	☐	☐	☐
I learned nothing from the problem.	☐	☐	☐	☐	☐
I had enough previous knowledge to solve the problem.	☐	☐	☐	☐	☐
I prefer solving problems on my own.	☐	☐	☐	☐	☐
We worked well together as a group.	☐	☐	☐	☐	☐
We did not share the work out evenly in our group.	☐	☐	☐	☐	☐
I found the group discussion helpful.	☐	☐	☐	☐	☐
At the end, we were not sure we had the correct answer.	☐	☐	☐	☐	☐
I could not have solved the problem by myself.	☐	☐	☐	☐	☐
I needed the other group members to help me remember background information	☐	☐	☐	☐	☐

Please answer the following questions.

After reading the problem,what did your group discuss first ? ....

....

What was the second step your group took to solve the problem? ....

....

....

What did you need to know before you began ? ....

....

....

What made it difficult for you to solve the problem?..

....

....

How did you overcome obstacles in the problem ? ....

....

....

The problem was quite difficult. What do you think you learned from trying to solve it?..

....

Endpiece

Now work on your own. Think about the problem you have just tried to solve.
Answer the following questions to show how you tackled the problem.

Please write your name here: ....

Tick the box that best describes your experience in tackling this problem.

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree
The problem was enjoyable.	☐	☐	☐	☐	☐
The problem was difficult.	☐	☐	☐	☐	☐
I found that solving this problem was satisfying.	☐	☐	☐	☐	☐
The problem was completely new to me.	☐	☐	☐	☐	☐
I learned nothing from the problem.	☐	☐	☐	☐	☐
I had enough previous knowledge to solve the problem.	☐	☐	☐	☐	☐
I prefer solving problems on my own.	☐	☐	☐	☐	☐
We worked well together as a group.	☐	☐	☐	☐	☐
We did not share the work out evenly in our group.	☐	☐	☐	☐	☐
I found the group discussion helpful.	☐	☐	☐	☐	☐
At the end, we were not sure we had the correct answer.	☐	☐	☐	☐	☐
I could not have solved the problem by myself.	☐	☐	☐	☐	☐
I needed the other group members to help me remember background information	☐	☐	☐	☐	☐

Please answer the following questions.

What did you need to know before you began ?

What made it difficult for you to solve the problem?

Appendix E

Word Association Tests (Two Booklets)

Name:

Word Association Test

Centre for Science Education

Page 1

When you hear or see a word, it often makes you think of other words. In this study we would like to find out what other words are brought to your mind by some words used in Chemistry.

On each page you will find a key word written many times. Say the word to yourself, and then as quickly as possible write the first word to comes to mind in space Number 1. And then continue to write in the other spaces other associated words which come to mind.

Continue in this way until you are told to turn the next page.

There are no right answers.

Write as quickly as possible since you are allowed only 30 sec. for each page.

Thank you very much.

EXAMPLE 1

EAGLE *

EAGLE	1............BIRD............
EAGLE	2............FLY...............
EAGLE	3............NEST............
EAGLE	4...........CLAW..........
EAGLE	5........FEATHERS.....
EAGLE	6............BEAK...........
EAGLE	7............BALD...........
EAGLE	8...........PREY............
EAGLE	9........PRESIDENT....
EAGLE	10..................................

Write as many words as come to your mind in the time available

EXAMPLE 2

ACID

ACID	1..........ALKALI..........
ACID	2......CONCENTRATION
ACID	3..........H+....................
ACID	4.........IONS................
ACID	5......LITMUS..............
ACID	6..........PROTON........
ACID	7..........SALT..............
ACID	8..........PH....................
ACID	9..................................
ACID	10..................................

Write as many words as come to your mind in the time available

OXIDATION

OXIDATION	1.................................
OXIDATION	2.................................
OXIDATION	3.................................
OXIDATION	4.................................
OXIDATION	5.................................
OXIDATION	6.................................
OXIDATION	7.................................
OXIDATION	8.................................
OXIDATION	9.................................
OXIDATION	10.................................

METAL

METAL	1.................................
METAL	2.................................
METAL	3................................
METAL	4................................
METAL	5................................
METAL	6................................
METAL	7................................
METAL	8................................
METAL	9................................
METAL	10..............................

OXYGEN

OXYGEN	1................................
OXYGEN	2................................
OXYGEN	3................................
OXYGEN	4................................
OXYGEN	5................................
OXYGEN	6................................
OXYGEN	7................................
OXYGEN	8................................
OXYGEN	9................................
OXYGEN	10..............................

ENERGY

ENERGY	1................................
ENERGY	2................................
ENERGY	3...............................
ENERGY	4..............................
ENERGY	5..............................
ENERGY	6...............................
ENERGY	7...............................
ENERGY	8..............................
ENERGY	9..............................
ENERGY	10.............................

REDUCTION

REDUCTION	1................................
REDUCTION	2................................
REDUCTION	3................................
REDUCTION	4................................
REDUCTION	5................................
REDUCTION	6................................
REDUCTION	7................................
REDUCTION	8................................
REDUCTION	9................................
REDUCTION	10................................

ELECTRON

ELECTRON	1................................
ELECTRON	2................................
ELECTRON	3................................
ELECTRON	4................................
ELECTRON	5................................
ELECTRON	6................................
ELECTRON	7................................
ELECTRON	8................................
ELECTRON	9................................
ELECTRON	10............................

OXIDES

OXIDES	1.................................
OXIDES	2.................................
OXIDES	3................................
OXIDES	4...............................
OXIDES	5...............................
OXIDES	6................................
OXIDES	7................................
OXIDES	8...............................
OXIDES	9...............................
OXIDES	10..............................

REDOX REACTION

REDOX REACTION	1................................
REDOX REACTION	2................................
REDOX REACTION	3................................
REDOX REACTION	4................................
REDOX REACTION	5................................
REDOX REACTION	6................................
REDOX REACTION	7................................
REDOX REACTION	8................................
REDOX REACTION	9................................
REDOX REACTION	10................................

BURNING

BURNING	1..............................
BURNING	2..............................
BURNING	3..............................
BURNING	4..............................
BURNING	5..............................
BURNING	6..............................
BURNING	7..............................
BURNING	8..............................
BURNING	9..............................
BURNING	10..............................

Name:

Word Association Test

Centre for Science Education

Page 1

When you hear or see a word, it often makes you think of other words. In this study we would like to find out what other words are brought to your mind by some words used in Chemistry.

On each page you will find a key word written many times. Say the word to yourself, and then as quickly as possible write the first word to comes to mind in space Number 1. And then continue to write in the other spaces other associated words which come to mind.

Continue in this way until you are told to turn the next page.

There are no right answers.

Write as quickly as possible since you are allowed only 30 sec. for each page.

Thank you very much.

EXAMPLE 1

EAGLE

EAGLE 1........BIRD........

EAGLE 2........FLY........

EAGLE 3........NEST........

EAGLE 4........CLAW........

EAGLE 5........FEATHERS........

EAGLE 6........BEAK........

EAGLE 7........BALD........

EAGLE 8........PREY........

EAGLE 9........PRESIDENT........

EAGLE 10..................................

Write as many words as come to your mind in the time available

Page 3

EXAMPLE 2

ACID

ACID	1. ALKALI
ACID	2. CONCENTRATION
ACID	3. H^+
ACID	4. IONS
ACID	5. LITMUS
ACID	6. PROTON
ACID	7. SALT
ACID	8. PH
ACID	9. ....
ACID	10. ....

Write as many words as come to your mind in the time available

COMBUSTION

COMBUSTION	1.................................
COMBUSTION	2.................................
COMBUSTION	3.................................
COMBUSTION	4.................................
COMBUSTION	5.................................
COMBUSTION	6.................................
COMBUSTION	7.................................
COMBUSTION	8.................................
COMBUSTION	9.................................
COMBUSTION	10.................................

OXIDES

OXIDES	1................................
OXIDES	2................................
OXIDES	3...............................
OXIDES	4..............................
OXIDES	5..............................
OXIDES	6...............................
OXIDES	7...............................
OXIDES	8..............................
OXIDES	9..............................
OXIDES	10..............................

FUEL

FUEL	1................................
FUEL	2................................
FUEL	3................................
FUEL	4................................
FUEL	5................................
FUEL	6................................
FUEL	7................................
FUEL	8................................
FUEL	9................................
FUEL	10...............................

OXYGEN

OXYGEN	1................................
OXYGEN	2...............................
OXYGEN	3...............................
OXYGEN	4..............................
OXYGEN	5..............................
OXYGEN	6..............................
OXYGEN	7..............................
OXYGEN	8..............................
OXYGEN	9..............................
OXYGEN	10.............................

ENERGY

ENERGY	1................................
ENERGY	2................................
ENERGY	3...............................
ENERGY	4...............................
ENERGY	5...............................
ENERGY	6...............................
ENERGY	7...............................
ENERGY	8...............................
ENERGY	9...............................
ENERGY	10..............................

BURNING

BURNING	1...............................
BURNING	2...............................
BURNING	3...............................
BURNING	4...............................
BURNING	5...............................
BURNING	6...............................
BURNING	7...............................
BURNING	8...............................
BURNING	9...............................
BURNING	10..............................

HEAT

HEAT	1................................
HEAT	2................................
HEAT	3................................
HEAT	4...............................
HEAT	5...............................
HEAT	6................................
HEAT	7................................
HEAT	8...............................
HEAT	9...............................
HEAT	10..............................

CARBON DIOXIDE

CARBON DIOXIDE	1................................
CARBON DIOXIDE	2................................
CARBON DIOXIDE	3................................
CARBON DIOXIDE	4................................
CARBON DIOXIDE	5................................
CARBON DIOXIDE	6................................
CARBON DIOXIDE	7................................
CARBON DIOXIDE	8................................
CARBON DIOXID	9................................
CARBON DIOXIDE	10...............................

Appendix F

Pupils' Answers

Unit 1 Argon and Electric Welding

Group 1 Welders torch used up all the oxygen from the air in the tank. The argon was useless to the welders torch as it is a noble gas. The oxygen is used up by the flame, and the air is displaced by argon. The men could not take in argon and had no air to breathe, therefor suffocating. (The argon comes from the torch)

Group 2 The gas in the torch could not have been argon, because it does not burn. So there must have been a hydrocarbon burning the oxygen in the torch, creating carbon dioxide which suffocated the men.

Group 3 Argon cannot burn, unreactive (noble gas), fuel could be a hydrocarbon such as methane. Oxygen used up from fueling the flame. When a hydrocarbon is burned it forms carbon dioxide and water, and carbon dioxide is poisonous. Due to lack of oxygen in tank, carbon monoxide was possibly produced which is even more poisonous than carbon dioxide.

Group 4 The detective is wrong in saying argon used up the oxygen in the tank as argon does not react with oxygen. We suggest that the gas used to weld the metal was a hydrocarbon gas eg methane or butane. The carbon would have reacted with the oxygen creating CO_2 (carbon dioxide). Carbon dioxide could have overcome the workers. For example,

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

Group 5 The workmen were using a hydrocarbon to weld, perhaps butane. The burning reaction used up the air in the tank and when a hydrocarbon is burned without enough oxygen, instead of forming water and carbon dioxide it formed carbon monoxide, which suffocated the men. It could not be argon as argon is unreactive and it is coloured, so the men would see it and escape.

Group 6 Argon doesn't burn, so it cannot be the fuel for the welder. Argon comes out and fills up the tank and pushed out the oxygen.

Group 7 Two men were suffocated in a tragic industrial accident, where they were in an unventilated tank and did not used efficient breathing apparatus. They died from lack of oxygen but not due to the argon gas as it does not burn.

Group 8 Argon is a noble gas, this means that it does not react with anything. The two workmen died because the argon gas filled up the tank and took away the supply of oxygen needed for the men to finish the job. As a result of this the men died.

Group 9 We do not think that argon was burned because it is a noble gas. We think a hydrocarbon was burned, which used up the oxygen in the tank. Another possible explanation is that when the hydrocarbon burned CO_2 and CO were produced which poisoned the workmen. We think the detective should have said" Burning methane gas in the welders torch apparently used up all the oxygen in the tank".

Group 10 There was only a limited supply of oxygen and they were in there so long they used up all of the oxygen and started breathing in carbon dioxide.

Group 11 As argon is a noble, unreactive gas, it cannot be burned. The gas was most likely to be a hydrocarbon(methane) gas as they are good fuels. When a hydrocarbon is burned carbon dioxide is released. Oxygen is used when burning occurs. These two things probably lead to the death of the men. The burning would use up oxygen and produce carbon dioxide suffocating the victims.

Group 12 Argon gas does not burn because it is one of the noble gases in the Periodic tables, so it is very unreactive. They suffocated because there was no oxygen left in the air because it had all been used up.

Unit 1 (Revised) Argon and Electric Welding

Group 1 The flame needed oxygen to burn and used up all the oxygen so he suffocated. The heat to burn the metal turn to steam and the steam filled in the tank and the oxygen was burned and he died from lack of oxygen.

Group 2 The two workmen died of fumes because a small fire. Used up all the oxygen because of a mistake one of the men made with the welder.

Group 3 We think that all the oxygen in the tank was used up by the workmen breathing and the blow torch. After all the oxygen was used up, the gas(argon) from inside the gas container escaped and the workmen died of asphyxiation. Burning argon gas from the welders torch apparently used up all the oxygen in the tank.

Group 4 Burning the oxygen gas means the oxygen is not full proof and the men could suffocated. The oxygen in tank was all used, mean oxygen level is not right. Air is made of : 0.03% carbon dioxide, 1% argon, 78% nitrogen and 21% oxygen.

Group 5 The workmen should not have been enclosed in the tank without an air vent or oxygen packs. Also they should have found another way for the welders to use their torches, as burning of a naked flames uses up oxygen.

Group 6 The oxygen in the tank was used up by the flame in the torch. The flame and the sparks for the electrical-welding need oxygen to burn and so used up all the oxygen in the tank. Leaving no oxygen for the welders to breath.

Group 7 A chemical reaction took place and the argon joined to make argon oxide compound and the men could not breath so they were suffocated. The mistake, they used too much argon when burning the welders flame.

Group 8 If the oxygen helps the argon gas burn, it acts as a catalyst and therefore is not used up. Pure oxygen is needed to burn but air has only 20% oxygen so the gas from the torch could not escape from the tank. The burners used up all the oxygen in the tank and they suffocated. When the argon burn in the air, the gas produced filled the tank and killed them.

Group 9 In order to melt the metal they used argon gas which used up all the oxygen in the tank. Things burn better in pure oxygen. It gave off strong fumes and there was not enough oxygen for them to breath. They used too much oxygen burning the gas or they did not have enough oxygen in the tank.

Group 10 The flame in the torch burned up all the oxygen in the tank because the flame needs oxygen to burn. Therefore there was no oxygen left in the tank, so the men suffocated.

Group 11 The welding torch which the men were using eventually used up all the oxygen which resulted in the men suffocated.

Group 12 Argon does not burn in oxygen. They didn't have enough oxygen. Argon is already in the air. The argon in the welders torch would not use oxygen.

Unit 2 Which is the Best Fuel?

Part 1

(1) $C + O_2 \rightarrow CO_2$
$C_{11}H_{24} + 18\ O_2 \rightarrow 12H_2O + 11\ CO_2$
$CH_4 + 5/2\ O_2 \rightarrow CO_2 + 2H_2O$

(2) Coal is $O_2 + C \rightarrow C$
Oil is $O_2 + 11\ C + 24\ H \rightarrow C_{11}H_{24}$
Gas is $O_2 + C + 4\ H \rightarrow CH_4$

(3) $C + O_2 \rightarrow CO_2$
$C_{11}H_{24} + 16\ O_2 \rightarrow 12H_2O + 11\ CO_2$
$CH_4 + 2\ O_2 \rightarrow CO_2 + 2H_2O$

(4) $2C + 2O_2 \rightarrow 2CO_2$
$C_{11}H_{24} + 17 O_2 \rightarrow 11 CO_2 + 12H_2O$
$CH_4 + 2 O_2 \rightarrow CO_2 + 2H_2O$

(5) $C + O_2 \rightarrow CO_2$
$C_{11}H_{24} + 6 O_2 \rightarrow 11 C + 12H_2O$
$CH_4 + O_2 \rightarrow C + 2H_2O$

(6) $C + O_2 \rightarrow CO_2$
$C_{11}H_{24} + 18O_2 \rightarrow 11 CO_2 + 12H_2O$
$CH_4 + 2 O_2 \rightarrow CO_2 + 2H_2O$

(7) $C + O_2 \rightarrow CO_2$
$C_{11}H_{24} + 17 O_2 \rightarrow 11 CO_2 + 2H_2O$
$CH_4 + 2 O_2 \rightarrow CO_2 + 2H_2O$

(8) $C + O_2 \rightarrow CO_2$
$C_{11}H_{24} + 17 O_2 \rightarrow 11 CO_2 + 2H_2O$
$CH_4 + 2 O_2 \rightarrow CO_2 + 2H_2O$

(9) $C + O_2 \rightarrow CO_2$
$C_{11}H_{24} + 11 O_2 \rightarrow 11 CO_2 + 2H_2$
$CH_4 + O_2 \rightarrow CO_2 + 2H_2$

(10) $C + O_2 \rightarrow CO_2$
$C_{11}H_{24} + 16O_2 \rightarrow 11 CO_2 + 2H_2O$
$CH_4 + 2 O_2 \rightarrow CO_2 + 2H_2O$

(11) $C + O_2 \rightarrow CO_2$ 1 molecule formed
$C_{11}H_{24} + 17 O_2 \rightarrow 11 CO_2 + 2H_2O$ 23 formed
$CH_4 + 2 O_2 \rightarrow CO_2 + 2H_2O$ 3 formed

(12) $C + O_2 \rightarrow CO_2$
$C_{11}H_{24} + 18 O_2 \rightarrow 11 CO_2 + 2H_2O$
$CH_4 + 2 O_2 \rightarrow CO_2 + 2H_2O$

Part 2

(1) Formula mass of carbon = 12x 1=12 g
Formula mass of oil = (12x11) +(24x1) = 156g
Formula mass of methane = (12x1) + (4x1) = 16 g

(2) Coal is 12, oil is 156, gas is 16.

(3) Coal is 12g, oil is 156g, gas is 16g.

(4) C = 12
$C_{11}H_{24}$ = 132 + 24 = 156
CH_4 = 16

(5) Coal is 12 + 32 = 44 g
Oil is 132 + 24 + 16 = 172 g
Gas is 12 + 4 + 16 = 32 g

(6) C = 12 amu
$C_{11}H_{24}$ = 145 amu
CH_4 = 16 amu

(7) Coal is 12, oil is 156, gas is 16.

(8) C= 12, $C_{11}H_{24}$ = 146, CH_4 = 15

(9) C= 12, $C_{11}H_{24}$ = 156, CH_4 = 16

(10) Coal = 12 amu, Oil =156 amu, CH_4 = 16

(11) Coal = 12, Oil = 156, Gas =16

(12) C= 12, $C_{11}H_{24}$ = 146, CCH_4 = 16

Part 3

(1) Oil gives out the greatest amount of energy as it has the most molecules formed. This is because there are more moles in the balanced equation.

(2) Our first answer is coal because its a solid. Our second answer is oil because it has a greater formula mass.

(3) 1000 / 12 = 83 mole,
1000 / 156 = 6.4 mole,
1000 /16 = 62.5 mole.
Therefore coal would give most energy.

(4) 1000 / 12 = 83 g,
1000 / 156 = 6.4 g,
1000 /16 = 62.5 g.
Therefore coal would give most energy.

(5) Coal 1000 / 44 =21,
Oil 1000 / 172 = 30,
Gas 1000 / 32 = 30.
Gas gives the most.

(6) Methane.

(7) Coal would give the most energy.
Coal 1000 / 12
Oil 1000 / 156
Gas 1000 / 16

(8) C= 83 amu, $C_{11}H_{24}$ =7amu, CH_4 = 67amu
Methane gives you most energy released because most molecules are formed in oil??

(9) Coal = 83, Oil = 6.5, Gas = 62.5
Coal gives the most energy.

(10) Coal 1 mole =44g, Number of moles in 1 kg= 1000/ 44 =20 moles roughly
Gas 1mole =64g, No od moles in 1 kg =1000/ 64 =15 moles roughly

(11) Coal = 1000/ 12= 83.3 x 1 = 83.3
Oil = 1000/ 156 = 7.15 x 23 = 161
Gas =1000/ 16 =62.5 X3 = 187.5
Gas would seem to give off the most energy.

(12) Coal

Part 4

(1) This is not a fair assumption because such factors on the bonding, structure and intermolecular forces have to be taken into account.

(2) Its not a fair assumption because each substance has its own strength no matter how many molecules are weaker substance has but the stronger would still release a lot more energy than.

(3) Yes. It is because coal formed most molecules.

(4) Yes. Because the smaller the molecules the more energy is released.
Because the less bond to break.

(5) Gas gives the most because it makes the most number of molecule in 1000 g of fuel.

(6) Bonds need energy to be broken and formed.

(7) We do not think this is a fair assumption. There could be large molecules formed but few of them and the energy could be more than if there was a lot of small molecules formed. The molecular size could vary giving different amounts of energy.

(8) It is a fair assumption because with more molecules there is more energy available to react with.

(9) No, one of the fuels is only one element and the other two contain hydrogen.

(10) No answer.

(11) We do not see this as fair. Gas gives out most energy in 1000g per molecule it is oil.

(12) Yes, it is a fair assumption because particles of carbon divide into 1000g.

Unit 2 Which is the Best Fuel? (Taiwanese Pupils')

Q1: What did you need to know before you began?

(1) Have strong knowledge about "Thermochemistry" (36);
(2) Basic chemical calaculations such as how to calculate formula mass and mole (37);
(3) How to write the balanced combustion equations (41);
(4) We needed to know what the influence of chemical equation by moles was (1);
(5) We needed to know what was the products (1);
(6) We needed to know how to use the chemical calculation to solve the problem (1);
(7) How to work out the Energy of Reaction and the variety of energy released (2);
(8) About mole and how to apply it (10);
(9) What was the combustion equation of each fuel (1);
(10) We needed the basic concept of thermochemistry to work out the demanded energy (1);
(11) We needed to know the atoms are reserved (1);
(12) Burning organic compound will produce CO_2 and H_2O (2);
(13) We needed to know the coefficient of chemical equation is equal to the mole ratio of each compound (2);
(14) General chemistry knowledge (13);
(15) The organic chemistry knowledge (2);
(16) The energy level (En) (2);

Q2: What made it difficult for you to solve the problem?

(1) We had difficulty in agreeing in the same solution (4);
(2) Not enough time (1);
(3) T hermochemistry (2);
(4) Part 3, because we needed to know what the products was and had to calculate the released energy / thinking (19);
(5) The combustion equation (1);
(6) Discussing the problem (2);
(7) Part 4, determining whether the assumption is fair. Especially we had to write our opinions / needed a profound concept and thinking / did not know how to answer it / did not have clear ideas / we had never done this kind of problem so we needed more time (16);
(8) It is difficult for me to decide which fuel was the best (3);
(9) Not difficult (1);
(10) Part 3 and Part 4, because we did not have clear ideas / the problem was abstract / we knew what the answer was but could not provide a reasonable explanation / the problem was unusual, we had to think it very long (7);
(11) All are difficult (1);
(12) We had never paced a problem like it before, so we did not know where to start (2);
(13) To construct our ideas (1);
(14) Part 3, first we used $E=mC^2$ but then thought the combustion eqautionie is related to the "thermochemistry" (2);
(15) We thought the energy released is related to the number of molecules formed (1);

Unit 4 Fluoride Improves Tooth Decay?

Group 1 They rewrote the statment: Fluorine strengthen tooth by bonding with calcium, the main element in enamel to form calcium fluoride, calcium fluoride is a harder, dense substance than calcium alone. Fluorine changed from fluoride, element changed from ingredient, substance changed from material.

Group 2 "Fluoride strengthens teeth by bonding with calcium", we think that this statement is false; " making teeth more resistant to bacteria that cause decay", because teeth are harder it does not make them more resistant to teeth.

Group 3 Calcium could be an ingredient in enamel but not the main one, fluoride has exactly bonded so it is impossible to form calcium fluoride.

Group 4 Fluoride is the main ingredient in enamel, calcium and fluorine are both contained in liquid therefore can not be hard and can not be dense as this would weigh you down, calcium fluoride is not an antibacterial liquid so this can not prevent decay.

Group 5 — Calcium reacts with water so it cannot be on it's own in your mouth, fluorine can be bonded to calcium but fluoride cannot.

Group 6 — Fluorine strengthens teeth by bonding with calcium not fluoride as it says, your teeth cannot contain calcium alone because calcium reacts with water (it has to be linked with something else), fluorine bonded with calcium is the main ingredient in enamel not fluoride as it says on the sheet.

Group 7 — Calcium is not the main ingredient in enamel, calcium is added to teeth to make them stronger, fluoride should be a fluorine because it is an element not a compound, " harder, dneser" does not make sense.

Group 8 — Fluoride is meant to be fluorine because it is a single element, calcium fluoride is less dense than calcium and softer because it is a solution.

Group 9 — The calcium would react with the water when you brushed your teeth etc. Fluorine is a gas and calcium is a metal, calcium fluoride is denser so it could not prevent the bacteria.

Group 10 — Fluoride is not the name of the unbonded element, its real name is fluorine. Calcium could not be on its own in your mouth as it would react violently with the moisture in your mouth, it is actually bonded with fluorine.

Group 11 — The teeth do not become more resistant to bacteria but more resistant to chipping.

Group 12 — In the first sentence it stated that fluoride bonds with calcium. This could not happen for fluoride is a compound and could not bond with anything else so it would only mix with the element calcium, fluoride mixing with calcium would not make teeth more resistant to bacteria for calcium is not the main ingredient in enamel.

Group 13 — It says " Improves Tooth Decay" , " Making teeth more resistant to the bacteria that cause decay".

Group 14 — Calcium is in your teeth not actually in the enamel, fluoride might not always strengthen teeth, calcium fluoide is not denser than calcium.

Group 15 — Wrong title, it should be "Fluorine fights tooth decay". Calcium is not main ingredient, 2 parts of fluorine to 1 part calcium, not fluoride but fluorine.

Unit 5 The Glowing Splint Problem

Group 1

Part 1

(a) Nitrogen dioxide is formed when the engine is ignited and a spark is formed.
(b) NO_2 is a factor of acid rain and air pollution which can corrode buildings.
(c) Diesel run cars do not spark, so NO_2 is not produced.
(d) sulphur dioxide.

Part 2

(1) There is the same amount of oxygen as before, but this time it relights a glowing splint.
(2) Nitrogen dioxide contains oxygen, so there is more than 20% oxygen present.

Group 2

Part 1

(a) Sparks inside the engine from the spark plugs.
(b) It can kill human being.
(c) By using a catalytic converter or using diesel gas.
(d) Nitrogen and oxygen.

Part 2

(1) It is because there is the same amount of nitrogen and oxygen as there is in air but it does re-kindle a glowing splint.
(2) The copper has reacted with it in some way.

Group 3

Part 1

(a) The mixture is sparked in the engine, oxygen and nitrogen from the air combine to make NO2.
(b) Air pollution affects eyes and lungs.
(c) Use a catalyst or a different petrol.
(d) Nitrogen and oxygen.

Part 2

(1) Because NO_2 does not re-kindle a glowing splint and it is made of 80% NO_2 and only 20 % oxygen.
(2) Because there is oxygen in the nitrogen dioxide.

Group 4

Part 1

(a) When air and fuel ignite the oxygen and nitrogen combine.
(b) It can cause acid rain which can corrode buildings and metal and kill plants.
(c) Add a catalytic converter.
(d) Carbon dioxide and carbon monoxide.

Part 2

(1) This is unexpected because the 20% of oxygen in air cannot re-kindle a glowing splint but the 20% in the gas produced can.
(2) Because there is lots of it.

Group 5

Part 1

(a) We think nitrogen dioxide gas is formed in the spark plug ignites the petrol.
(b) NO2 can cause acid rain which corrodes buildings and kills plants.
(c) NO2 can be solved by fitting a car with a catalytic converter.
(d) Carbon dioxide is produced when NO_2 is removed.

Part 2

(1) The result is unexpected because air contains 20% oxygen as well.
(2) A possible explanation is that nitrogen dioxide contains oxygen so the percentage of oxygen when together is higher than 20% so it can relight the glowing splint.

Group 6

Part 1

(a) The spark from the engine has enough energy to ignite the nitrogen in the air making it bond with the oxygen in the air making NO_2.
(b) It can cause acid rain which stunts growth in trees, causes the acidity of lakes and rivers to rise killing animals.
(c) Use alternate fuels: solar, wind, nuclear, fission etc, or use a catalytic converter.
(d) Carbon dioxide is formed, sulphur dioxide is formed.

Part 2

(1) This is an expected result because it contains 80% nitrogrn dioxide, but in the statement it states that NO_2 does not relight a glowing splint.
(2) The oxygen in the NO_2 added to the 20% oxygen, there could be enough O_2 to relight the glowing splint.

Group 7

Part 1

(a) Nitrogen dioxide is caused by a car engine sparking.
(b) The effects of this is that it causes damage to buildings, kills plants and sea life and it is harmful to people with asthma.
(c) To solve this problem use a catalyst fitted to the car exhaust when NO2 is removed.
(d) Carbon dioxide and sulphur dioxide is fromed.

Part 2

(1) This was an unexpected result because there was more nitrogen dioxide than oxygen.
(2) A possible explanation for this is that there is oxygen in nitrogen dioxide, this means the oxygen has been increased therefore it will allow a glowing splint to be rekindled.

Group 8

Part 1

(a) Nitrogen reacts with oxygen in a car engine which forms nitrogen dioxide.
(b) NO_2 causes acid rain.
(c) The problems of NO_2 can be solved in a car by fitting a catalytic converter.
(d) When NO_2 is removed from the car exhaust the gases that are formed lead vapor.

Part 2

** No answer.

Group 9

Part 1

(a) No answer.
(b) Acid rain.
(c) Catalytic converter.
(d) Catalyst must break up.

Part 2

(1) Because its like air but did rekindle a glowing splint.
(2) No answer.

Group 10

Part 1

** No answer.

Part 2

(1) It is unexpected because air, which contains 20 % oxygen doesn't relight a glowing splint but the gas from the test tube, which also contains 20% oxygen relights a glowing splint.
(2) Adding a catalyst breaks up the nitrogen dioxide into nitrogen and oxygen which gives more oxygen gas to relight the glowing splint.

Unit 5 (Revised) The Glowing Splint Problem

Question:

Group 1 When NO_2 is broken up it breaks up into nitrogen and oxygen.

Group 2 Nitrogen and oxygen are formed when NO_2 is broken up in the exhaust.

Group 3 N_2 and O_2.

Group 4 Nitrogen and oxygen are formed when nitrogen dioxide is broken up in the exhaust.

Group 5 N_2 , O_2 and carbon monoxide.

Group 6 Nitrogen dioxide could be broken down into its two component gases nitrogen and oxygen.

Group 7 No answer.

Group 8 No answer (repeat writing the question).

Group 9 The gas which are formed from NO_2 in a car exhaust would be nitrogen and oxygen.

Group 10 It forms nitrogen and oxygen.

Problem (1) and (2)

Group 1

(1) This result is unexpected because the percentages of gases released are equal to air which does not relight a glowing splint.

(2) The reason for the splint re-lighting is that 20% oxygen plus the oxygen from the NO_2 breaking up with the heat is enough oxygen to re-light a glowing splint.

Group 2 (1) This is an unexpected result because we are told NO_2 will not rekindle a glowing splint but after heating the gases, the gases coming out of the test-tube one of them being NO_2 will rekindle a glowing splint.

(2) A possible explanation for this is that the catalyst on the end of the glowing splint is breaking up the NO_2 which is helped by the heat. Thus producing more oxygen allowing the splint to rekindle.

Group 3 (1) Because when NO_2 is broken up, air comes out and air will not relight a glowing splint but this does.

(2) We think its because it has been heated and heat speeds up a reaction. And you get more oxygen from nitrogen dioxide it reeps giving off the oxygen. Oxygen from the NO_2 breaks up by cracking.

Group 4 (1) It is unexpected because air has 80% nitrogen and 20% oxygen, this is not enough to relight a splint. Moreover, the products of the experiment could relight it even though it had the same percentages of nitrogen and oxygen.

(2) No answer.

Group 5 (1) The fumes relight a glowing splint when we predicted it would not.

(2) The catalyst breaks the NO_2 into nitrogen and oxygen plus the other 20% oxygen which means there will be more oxygen which will rekindle a glowing splint.

Group 6 (1)The result of this experiment is unexpected because gases from the test tube only contain the same amount of oxygen as is in the atmosphere.

(2) A possible explanation for this is that the heat from the glowing splint breaks down nitrogen dioxide into nitrogen and oxygen producing enough oxygen to relight the glowing splint.

Group 7 (1) It is an unexpected result as although the nitrogen dioxide rekindle the glowing splint this is not meant to happen.

(2) The glowing splint acts as a catalyst and breaks up the nitrogen dioxide causing the reknidle of the splint.

Group 8 (1) Because there is a substance which acts as a catslyst.

(2) The glowing splint acts as a catalyst and to break up nitrogen dioxide to release more oxygen to relight the glowing splint.

Group 9 (1) In experiment 1, it showes that nitrogen dioxide does not rekindle a glowing splint but in experiment 2, it does rekindle a glowing splint so the result is unexpected.

(2) The glowing splint acts as a catalyst to break up the NO_2 into oxygen and nitrogen, which leaves is with 46% oxygen enough to relight a glowing splint.

Group 10 (1) It states that air or NO_2 will not rekindle a glowing splint but in part 2 it says that these do rekindle a splint, this is why it is unexpected.

(2) When NO_2 is breaking up it gives off more oxygen to the air and we all know when a glowing splint is entered to a test tube of oxygen it will rekindle. This is a possible explanation for this experiment.

Unit 6 Heat Packs for Mountaineers

Problem (1)

Group 1 By rubbing your hands with the heat pack it is heated up enough for a reaction to occur, and because it is an exothermic reaction it is self-sustaining. The iron will react with the air producing $Fe_2 O_3$.

Group 2 When you open the airtight bag the air gets in and starts the reaction, when you shake it, it mixes the reactant together and the moist cellulose acts as a conductor to draw the heat away from the core. The iron powder is the raw reactant.

Group 3 When the bag is opened, air gets in. The oxygen in the air then mixes with the iron and when you rub it the cellulose it moistens the salt and speeds up the reaction allowing electron movement. The carbon also helps the reaction. The powdered iron speeds up the reaction.

Group 4 The heat pack works by someone rubbing the pack. When this happens, the main material (fine iron powder) reacts with the air inside and the porous fabric lets the heat escape through it giving off heat.

Group 5 Oxygen in the air combines with iron and gives energy which is then converted to heat energy. When the bag is rubbed , the heat is travelled through the porous fabric onto the hand which then keeps the person worm.

Group 6 The heat pack works when oxygen reacts with fine iron powder, the other three components are catalysts. The heat energy comes from the reaction.

Group 7 As you rub your hands together, the particles collide with each other and move from positive ions to negative ions which produces the heat energy. The oxygen comes through the porous so when you rub your hands it produces fabrics heat energy which kick starts the reaction.

Problem (2)

Group 1 Iron is used as it is a good reactant and it is a cheap metal. Zinc can also be used as it is a good reactanrt and is cheap.

Group 2 Iron powder is the main material because it is cheap and it is a good reactant with oxygen. Manganese is also another metal that has similar chemical properties to iron. Therefore it can be used as a substitive for iron.

Gropu 3 Iron is used because it rusts quickly and is speeded up by salt. Aluminium or lead could be used because they corrode quickly.

Group 4 Iron is used because it reacts with oxygen from the air in a good manner. It will give the right temperature and it will be safe when reacting. Zinc will be another suitable element since it is similar to iron when reacting with oxygen.

Group 5 Iron powder is used as a main product because metal reacts with oxygen much easier. zinc could be used instead of iron as its not poisonous and does not react faster than other chemicals.

Group 6 Zinc could be used. Iron used because it reasonably reactive and not poisonous.

Group 7 We use iron because iron is a heat conductor, because it is not a finite resource.
Copper -- radiator, cheap metal to get hold off.
Aluminium-- foil, to keep everthing warm, very light.
Carbon-- stops buildings from corroding.

Unit 8 Moving Gases

Group 1 (1) We worked out all the atomic masses and found out that the higher the mass the lower the distance it travelled.
(2) We can take a gas with a higher atomic mass and one with a lower mass and see if the pattern continues by carrying out the same test upon it.
(3) The atomic mass of chlorine is 71 which higher than SO_2 and lower than SO_3, so it had to be in the middle because the difference is 16. Chlorine travells at 47 cm.

Group 2 (1) Sulphur plus oxygen compounds travel between 44 and 50 cm and the more oxygen contained in the compound the less distance travelled. The lower the relative atomic masss the more distance travelled. CH_4 has the lowest mass (16) but the highest distance travelled at100 cm. SO_3 has the highest mass (80) and the lowest distance travelled at 40 cm.
(2) We would test this theory by using a coloured gas with a high mass and put it in a tube for a certain amount of time and measure how far it has gone. We will do the same for another coloured gas with a low mass and leave it for the same amount of time under the same conditions and then measure the distance travelled.
(3) I expect for Cl_2 that it will travel between 50 cm and 44 cm because its mass is 78 which between the mass of SO_2 (64) and SO_3 (80) and they had travelled 50cm (SO_2) and 44cm (SO_3).

Group 3 (1) The higher the atomic mass, the less distance the gas travels.
(2) Try the experiment with other gases.
(3) The gas Cl_2 will travel 47 cm.
Pupils' notes:
a. Atomic mass affect distance travelled.
b. Drew a picture of outer shell of atom.

Group 4 **(One member of this group drew a graph)**
(1) The lighter the gas compound the further it travels in a set amount of time.
(2) You could work out the weight of the different gas and find out the speed they travel throgh air this would show our pattern.

(3) We found that the lighter the gas the faster it travels through air, and think Cl_2 will cover at distance in the set time of about 47.4cm according to our graph.
Pupils' notes:
a. the way of prediction: 80 - 64 = 16 ; 50 - 44 = 6
16 / 6 =2.7, closer to 50 cm
b. the graph shown below:

Group 5 No answer.
(But they correctly calculated the formula mass of each gas)

Group 6 (1) We tried to relate gram formula mass to distance travelled and our conclusion was that the lighter the mass the further it travelled.
(2) To find out if this pattern is correct we could separate the groups into the furthest distance and made sure they weighed less than the shorter distance gas.
(3) It will travell at 150 cm as its mass weight is 71. (**Where is the value 150 from? They wrote: Cl =35.5 x 2, so 71 x 2 = 150.**)

Group 7 (1) The lighter the gas is the further it will travel and the heavier the gas is the least it will go.
(2) The heaviest gas is chloride.
(3) No answer.
(But they correctly calculated the formula mass of each gas.)

Group 8 (1) The pattern we have noticed from the table is : The lighter the compound is, the further that it will travel. e.g. SO_2 (mass is 64) travelled 50 cm and CH_4 (mass is 16) travelled 100cm.
(2) You would test a light gas and a heavy gas. Set them up in the experiment and see how long each will travel in one hour.
(3) Between 44 and 50 cm; because Cl_2 is lighter than SO_3 which travelled 44 cm and heavier than SO_2 which travelled 50 cm.

Group 9 (1) The higher the distance the lower the mass is and the smaller the distance the higher the mass.
(2) No answer.
(3) No answer.
Pupils' note: they simply used two gases to compare it. CH_4 has the highist distance, SO_3 has the smallest distance.

Group 10 (1) The lighter the gas, the further it travels. The heavier the gas, the shorter it travels.
(2) No answer.
(3) No answer.
Pupils' notes: they just calculated two gases' formula mass, but the datas were incorrect. SO_2=32 + 16 + 2 =50; HCl = 1 + 35.5 =36.5 x 2 = 73.

Group 11 (1) The lighter the compound the further it will go. The heavier the gas the less it will go.
(2) No answer.
(3) No answer.
Pupils' note: they did not completely calculate the formula mass of each gas.

Group 12 (1) The heavier the gas the less distance it travels. The lighter the gas the longer it travels.
(2) No answer.
(3) Between 45 cm and 49 cm.
Pupils' notes: they correctly calculated the formula masses of gases.

Unit 8 (Revised) Moving Gases

Question (1)

Group 1 (1) The lighter the gas the further the distance it may travel.
(2) The gases are perfumed so if you put a gas at one end of the room and timed how long it takes for you to smell it, then you could find out which gas travels the quickest.
(3) Cl_2 would be very slow because Cl=35.5 but doubled =71. The gas is heavier.

Group 2 (1) The heavier the molecule is, the less distance it travels.
(2) Take more molecules, work out their weight and the distance they travel and work out whether our hypothesis is correct.
(3) No answer.

Group 3 (1) The gas with hydrogen travels the furthest because it is the lightest. The gases with sulphur and oxygen in them travel the least because they are two of the heaviest.
(2) Line people at 40 cm, 50 cm, 60 cm, 70 cm, 80 cm, 90cm and 100 cm away from the gas, let off each gas after each other wait until the last about 25cm.
(3) About 25 cm.

Group 4 (1) The denser the substance's relative atomic mass, the slower it travels. The lighter, the faster.
(2) I would test to see if CO_2 travelled between 66 and 94 cm in the same conditions.
(3) 44 - 47cm under the same conditions.

Group 5 (1) The lower the molecular mass of the gas the further distance is travelled.
(2) No answer.
(3) Roughly 44 cm. It is the same as SO_3.

Group 6 (1) The higher the formula weight of the compounds the less distance it travels as it is heavier. One oxygen weighed the same as a methane molecule.
(2) No answer.
(3) No answer.

Group 7 (1) The heavier the atom the less distance travelled.
(2) The experiment would be done again with oxygen and hydrogen to see if and H_2 are the causes of the distance travelled.
(3) No answer.

Group 8 (1) The lighter the molecule is the further distance it can travel. For example, SO_2 weighs 64 g and only travels 50 cm but methane (CH_4) weighs 16 g and travels 100 cm.
(2) No answer.
(3) 45 cm we would expect it to travel.

Group 9 (1) When you calculate the relative atomic masses for each substance the higher the added number the slower the substance travels.
(2) Set up the same experiment with different molecules, calculate their molecular weight and their distance with the experiment.
(3) The group believe it will go 54 cm.

Group 10 (1) As the molecular mass increases the distance travelled decreases.
(2) No answer.
(3) No answer

Group 11 (1) All even numbers. The longer the distance travelled the lighter the molecule.
(2) You would test it by using different gases of different weight into a tube and measure the distance travelled in a certain amount of time. You need to know the weight of 1 mole of gas and compared it with the others.
(3) It would travel approximately 45 cm.

Group 12 (1) The lighter they are the further they travel.
(2) Test more gases.
(3) 46 cm.

Group 13 (1) If there is a di-oxygen in the formula then it would be half in methane. If you add up relative atomic mass sulpher dioxide the distance travelled. The more the gas the less distance it would travel.
(2) Test how far another gas would go. Test it through in a gas tube.
(3) You would expect to travel.

Group 14 (1) We found out that the gases with higher GFM (gram formula mass) went less in distance and the ones with lower GFM went more further indistance.
(2) You would test different gases.
(3) 71 was the GFM, so we guessed that 97 (cm) would be the distance.

Unit 10 The Phosphorus Problem

Goup 1 Melt at -90 °C, then boil at 280 °C, then boil at -191°C, then melt at ~1540 °C.

pupil's notes:
a. Put SiF_4 in water to make it disappear.
b. To get rid of SiF_4 put it in water and it should react and hopefully disappear, $CaSiO_3$ melt.

Group 2 To separate $CaSiO_3$ from the gases you would use the method of filtration. P_2 by centrifuging.

Group 3 To get pure phosphorus solid we will melt $SiF_4(g)$ and burn $CO(g)$ in air; and because $CaSiO_3$ (s) is a solid we would filter it by hand and melt $P_2(g)$ and then freeze it so we would be left with pure phosphorus solid.

Group 4 We started getting rid of SiF_4 by putting it in water. We then got rid of the CO by putting it in ammonia and freezing it at -199°C. We then filtered the $CaSiO_3$ out and got the gas in conical flask with a gas that it does not react with.

Pupil's note: 2.90 + 1.82 =5.72 in his white paper. (use density)

Group 5 No answer.

Group 6 Put the mixture into water and you are left with $CaSiO_3$ and P_2 as a solid, then heat at 44 °C and keep the solution P_2, then store the gas P_2 and cool until it is a solid.

Group 7 Freeze it in liquid nitrogen to -80°C then pump out the liquid nitrogen.

Group 8 If we want to get pure phosphorus we would cool the three gases to 44 °C, then the other two would escape into the atmosphere. We would then cool the phosphorus under water about 30 °C degrees. Then put a small jar under the water to scoop up the solid, from there you would put this in a glove box, open the jar and let the phosphorus and the water out to let the solid dry off. This is how we would solve this problem.

Pupil's note: they drew a glove box picture.

Group 9 Mix four compounds with water, then

SiF_4: Reacts in water,

CO: Escapes as a gas in water,

P_2: Changes to a liquid, lies in bottom of melt. Cool water under 44 °C.(it turns to crystals, lies at bottom of water.)

Keep P_2 under water as when it is taken out of water it will explode.

$CaSiO_3$: no reaction.

Group 10 Add water to the compounds to remove SiF_4. Boil the compounds to -191°C to remove CO. Boil the compounds in an airtight room then separate the $CaSiO_3$ from P_2 by distillation. Keep the compounds in an airtight box with gloves attached to the side for your hands.

pupils' note: P_2 burns violently.

Group 11 Put it under water and you would get rid of SiF_4 and left with two compounds (CO + P_2). When CO escapes, then you cool down P_2 as a liquid and it turns into a solid.

Group 12 You could freeze off the P_2 at 44 °C and it would be solid.

pupil's note: Phosphorus explodes in air, so keep it under water.

Unit 12 Salt, salts and pH

Group 1

(1) The conclusion we have come to is that all the salts containing(II) e.g. Iron (II) sulphate are acidic, with a pH of no more than 3.

(2) Nitrate, chloride and sulphate salts all contain a pH of 7 or less.

(3) All the potassium salts had a pH between 7 and 11.

(4) All the carbonate salts had a pH of either 10 or 11.

Group 2

(1) Any salt containing sulphur has a pH of < 7.

(2) Any salt containing sodium has a pH of > 7.

(3) Any salt containing carbon has a pH of > 10.

(4) Any salt containing chlorine

(5) Any salt containing potassium

(6) Any salt containing calcium

(7) Any salt containing nitrogen

Group 3

(1) Salts containing chloride seem to have a pH < 7.

(2) Salts containing carbonate seem to have a pH > 10.

(3) Nitrate salts don't go below pH of 3.

(4) Only one salt contains sodium and has a pH of 10.

(5) All the salts with the (II) sign have a pH < 3.

Group 4

(1) All salts containing sulphate, nitrate and chloride have a pH of 7 and less. We say that the pH > 7.

(2) All salts containing carbonate have a pH of 10 or more. We say that the pH < 10.

(3) All salts containing sodium and potassium have a pH of 7 or more. We say that the pH < 7.

(4) All salts containing iron have a pH of 1.

(5) All salts containing aluminium, zinc,and copper have a pH of 3.

(6) All the salt solutions with an acidic pH contains transition metals.

(7) All the salt solutions with a pH of 7 or more contain alkali metals.

Group 5

(1) Sulphates pH < 7.

(2) Potassium pH > 7.

(3) Nitrates pH< 7.

(4) Carbonate pH > 10.

(5) Sodium pH > 7.

(6) Carbonates are the only alkalines.

(7) The acidic salts have no alkali metals in them.

Group 6

(1) Anything with carbon in it is an alkali.
(2) Any compound with sodium in it has a pH of 7 or more.
(3) Anything with transition metals are acidic.
(4) Anything with chloride has a pH less than 7.

Group 7

(1) The salts pH relate to the non-metals position in the periodic table more than to the metal.
(2) Salts containing sulphur have a pH of 7 or less.
(3) Salts containing carbonate always have a alkali pH.

Group 8

(1) All the substances which contain sulphate have a pH < 7.
(2) All the substances which contain carbonate have a pH > 10.
(3) All the substances with (II) have a pH < 7.
(4) All the substances which contain sodium have a pH > 7.
(5) All the substances which contain chloride have a pH < 7.
(6) All of the non-metals have a higher pH than the metals.

Group 9

(1) Sodium a metal in group 1 will have a pH greeter than or equal to 7 in a salt.
(2) Sulphate has a pH which is smaller than or equal to 7.
(3) Chloride, non-metal in group 7 when in a salt has a pH smaller than or equal to 7.
(4) Carbonate a non-metal in grooour 4 has a pH greater than or equal to 10.
(5) Nitrate a non-metal in group 8 has a pH smaller than or equal to 7.

Group 10

(1) Salt contains carbonate have a pH of 10 or more.
(2) Salt contains sulphate have a pH of 7 or less.
(3) Salt contains (II) have a pH of 3 or less.
(4) Salt contains nitrates have a pH of 3 or more.
(5) Salt contains chlorides have a pH of 3 or more.

Group 11

(1) Salts that contain sulphur have a low pH, while salts that contain chlorine also have a low pH. These kinds of salts are acidic.
(2) Salts containing sodium have a high pH and salts that contain carbon are strong alkalis.
(3) Salts containing nitrogen have an acidic pHof 3 to 7.

Group 12

(1) The carbonates have a higher pH level of 7.
(2) The sulphates have a lower pH level of 7.
(3) The chlorides have a pH level of 7 or under.
(4) The nitrates have a lower pH level of 7.

Group 13

(1) Sulphates, chlorides and nitrates are all acidic or neutral.
(2) Carbonate produce only alkali.
(3) Sodium and potassium produce alkali solution and they are alkali metals.
(4) Aluminium, zinc and copper are shiny metals and they produce an acidic solution.

Group 14

(1) Sulphate pH < 7.
(2) Carbonate pH> 10.
(3) Chloride pH < 7.
(4) Sodium is either alkali or neutral.

Group 15

(1) Salt containing sulphur(S) seem to have the pH < 7.
(2) Salt containing chlorine(Cl) seem to have the pH < 7.
(3) Nitrogen(N) has a pH of , 7.
(4) Carbon(C) has a pH of > 10.
(5) Iron(II) in salt has a pH of 1.
(6) Aluminium in salt has a pH of 3.
(7) Zinc (II) in salt also has a pH of 3.
(8) So does copper, sodium and potassium in salt have a pH of > 7.

(9) With calcium in salt having a pH of only 7.
(10) All salts are made of a metal and a non-metal.

Group 16
(1) We found carbonates had a pH > 10.
(2) Potassium pH > 7.
(3) Sulphate pH < 7 and nitrate pH < 7.
(4) So our conclusion is one of the groups of salts (carbonate and potassium) have a pH value of 7 or over and the other group(sulphate and nitrate) have a pH of 7 or less.

Group 17
(1) Sodium salts have the pH >7.
(2) Salts containing sulphur has the pH< 7 and are acidic.
(3) Salts containing chlorine has the pH< 7 and are acidic.
(4) Salts containing nitrgen has the pH< 7 and are acidic.
(5) Salts containing carbon has the pH> 10 and are alkalis.

Group 18
(1) Salts containing sodium have a pH more than 7.
(2) Salts containing carbonate have a pH more than 10.
(3) Salts containing sulphate have a pH less than 7.
(4) Salts containing chloride have a pH less than 7.
(5) Salts containing nitrate have also a pH less than 7.
(6) Double bonding power metals seem to have a low pH.

Group 19
(1) Salts containing carbon--pH >10.
(2) Salts containing sulphur--pH < 7.
(3) Salts containing sodium--pH >7.
(4) Salts containing nitrgen--pH < 7.
(5) Salts containing chlorine--pH < 7.
(6) Salts containing oxygen--pH < 11.
(7) We think the lesser the group number of the two elements from the compound the higher the pH. ie. potassium carbonate high pH= 11(strong alkali).

Group 20
(1) All the alkali metals in the table produce a neutral or alkali solution but transition metals produce acidic solutions.
(2) All group 1 metals will make an alkali solution.

Unit 13 Solubility

Group 1 No answer.

Group 2 (1) The elements with a bonding power of one, a large percentage were soluble.
(2) If we mixed magnesium chloride to potassium hydroxide, the physical state will change and solubilities reversed.
(3) No answer.
(4) No answer.

Group 3 (1) a. Top two lines are soluble.
b. All nitrates are soluble.
c. The majority of CO_3^{2-} are insoluble.
d. The Pb^{2+} line is all in soluble apart from NO_3^-.
(2) No answer.
(3) No answer.
(4) They will be insoluble.
strontium hydroxide = 2, strontium sulphate = 0.01.

Group 4 (1) a. Na^+ are all slightly soluble.
b. K^+ are soluble.
c. NO_3^- are all soluble.
d. SO_4^{2-} there is a mixture of solubilities.

(2) No answer.
(3) No answer.
(4) Strontium hydroxide is slightly soluble, strontium sulphate is slightly insoluble.

Group 5 (1) a. For CO_3^{2-} it has very low solubility.
b. Na^+ is mainly soluble in every solution.
c. Pb_2^+ has mainly very low solubility in solution.
d. NO_3^- is a normally very soluble solution.
(2) No answer.
(3) No answer.
(4) Strontium hydroxide would be insoluble.

Group 6 (1) a. All the K^+ are soluble.
b. Na^+ is always soluble or slightly soluble.
c. Most CO_3^{2-} are insoluble.
d. Pb_2^+ is nearly always insoluble.
(2) No answer.
(3) No answer.
(4) Strontium hydroxide = 7.08, strontium sulphate = 0.02.

Group 7 (1) a. All top two lines are soluble.
b. All NO_3^- are soluble.
c. Most CO_3^{2-} are insoluble.
(2) No answer.
(3) No answer.
(4) Strontium hydroxide = 10, strontium sulphate = 0.02.

Group 8 (1) a. Sodium and potassium are always soluble.
b. All nitrogen compounds are soluble.
c. Most neutral charged carbon compounds are insoluble.
(2) No answer.
(3) No answer.
(4) Strontium hydroxide will be slightly soluble, strontium sulphate will be insoluble.

Group 9 (1) a. Every nitrate is soluble.
b. Every sodium is soluble.
c.Lead is insoluble with the exception of the nitrate.
d. Potassium is completely soluble.
(2) It stays soluble.
(3)You would put the solution into a hydroxide solution so that the sodium would dissolve and you could extract it.
(4) Strontium hydroxide is slightly soluble, strontium sulphate is insoluble.

Group 10 (1) a. The alkali metals are soluble in all compounds.
b. CO_3^{2-} is insoluble except with alkali metals.
c. NO_3^- is very soluble with all compouns.
d. OH^- is insoluble with the transition metals.
e. F^- is insoluble with group (II) metals.
f. Cl^- is very soluble with group (II) metals.
(2) $Mg^{2+}\,Cl^- + KOH \longrightarrow K^+Cl^-$ (dissolved) $+ Mg^{2+}\,OH^-$
which would be a liquid of potassium chloride and a solid of magnesium hydroxide.
(3) We would add sodium carbonate to the solution with lead nitrate and sodium nitrate. The carbonate would react with lead and form a solid which would collect at the bottom. All that would be left are sodium and nitrate ions.
(4) Strontium hydroxide is soluble, strontium sulphate is insoluble.

Group 11 (1) a. The closer the compound is to be neutral, the more soluble it is.
b. Nitrates are all soluble.
c. Lead is not soluble except with nitrate.
(2) More potassium hydroxide will dissolve.
(3) Sodium nitrate.
(4) Strontium hydroxide is slightly soluble and strontium sulphate is insoluble.

Group 12 (1) a. Sodium salts are mostly soluble.
b. Nitrate salts are mostly soluble.
c. Carbonate salts are insoluble except the alkali metal salts.
d. Lead salts mostly insoluble except lead nitrate.
(2) Increases solubility.
(3) Add carbonate to lead nitrate.
(4) It should not be very soluble because most strontium are not soluble.

Unit 13 (Revised) Solubility

Group 1 (1) Gradually moving down the graph, there are more soluble elements / ions thanat the top.
(2) Strontium hydroxide: prediction 10-11, agreed answer is 10.
Strontium sulphate: prediction 0.001-0.09, agreed answer is 0.001.
(3) No answer.

Group 2 (1) All sodium compounds are soluble or slightly soluble.
All potassium compounds are soluble.
All nitrogen oxide compounds are soluble or slightly soluble.
Most carbonate compounds are insoluble.
(2) No answer.
(3) Magnesium chloride and potassium hydroxide are soluble, so the mixture would be soluble also. 112 + 54 = 166 makes it soluble.

Group 3 (1) All Na^+ compounds are soluble.
All K^+ compounds are soluble.
All compounds which contain NO_3^- are soluble,
All CO_3^{2-} are soluble apart from Na^+, K^+.
(2) Strontium hydroxide = 5, between Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+} the solubility increases each time from 0.0009 to 0.16 to 14, so it has to be in between 0.16 and 14.
Strontium sulphate = 0.01, the opposite happens it decreases from 33 to 0.21 to 0.0002.
(3) When added the solubility decreases.

Group 4 (1) Na^+ and K^+ are both alkali metals (column 1), both have one outer electron and are very reactive. They also have the same propertis and are soluble in all of the compounds given.
Mg^{2+}, Ba^{2+} and Ca^{2+} are in column 2 and are very similar in their reactions with each compounds.
Pb^{2+}, Zn^{2+}, Ag^+ and Fe^{2+} are all transition metals and their properties vary in each compound. Therefore, their solubilities are vary.
(2) We would expect strontium hydroxide to have a solubility of 5, because it is between calcium and barium in the Peroiodic Table (P.T). so its solubility is between them (0.16 to 14).
We would expect strontium sulphate to have a solubility of 0.02, again due to the fact that Sr is between Ca and Ba in the P.T, so its solubility is between them (0.21 to 0.0002).
(3) The magnesium would not dissolve completely in the mixture as it is very insoluble in OH^-. The K^+ would be soluble in the mixture as it is soluble in both OH^- and Cl^-.

Group 5 (1) Na^+: all soluble , apart for F^- which is slightly soluble.
K^+: all soluble.
Mg^{2+}: half are soluble, very small numbers.
Ca^{2+}: mostly soluble.
Ba^{2+}: only 2 are soluble.
Pb^{2+}: 5/6 are soluble.
Zn^{2+}: 3/6 are soluble.
Ag^+: half are soluble, 1 decomposed.
Fe^{2+}: varied (3 soluble, 1 insoluble, 1 not known).
(2) Strontium hydroxide: between 0.16 - 14, guess it is 6-7.
Strontium sulphate: guess 0.02.
These answers were found by taking roughly 1/2 the numbers between Ca^{2+} and Ba^{2+}.
(3) Both are soluble, there would be an extreme reaction giving off gases.

Unit 14 The Swimming Pool Problem

No.1
---Water warm, clean, not too heavily chlorinated.

No.2
---Warm, clean, smell nice, not to taste bad, to be clear.

No.3
---Warm water, clean water, filters urine detector, water which doesn't hurt your eyes.

No.4
---Clean, not overly chlorinated, smellers, it should be colorless.

No.5
---No smell, clean, doesn't sting your eyes, clear.

No.6
---Not too much chlorine so it doesn't sting your eyes. The water must not be cloudy, must not have a horrible taste, must not smell.

No.7
---Chlorine, clean, a good temperature, safety(enviroment) maintenance.

No.8
---Warm, smells nice, kind to your skin, clean, safe, wet, nice colour.

No.9
---Clean, doesn't smell, doesn't hurt eyes or give rashes.

No.10
---Hot water, clean water, nice smelling.

No.11
---The temperature of the water, enough chlorine in the water to make it safe.

No.12
---Not an excessive temperature, clean, lifeguards.

No.13
---Not too cold, but not too warm either. The water to be about pH neutral with the body's skin, but must be able to kill bacteria.

No.14
---pH of around 5.5, not unpleasant smell, enough chlorine to kill bacteria without harming swimmery, clear and natural water.

No.15
---The water to be fresh and clean, to smell nice, not to irritate your eyes.

No.16
---A sufficient volume of chlorine.

No.17
---No germs, doesn't irritate eyes.

Part 2

No.1

a. $HCl \rightarrow H^+ + Cl^-$
$HOCl \rightarrow H^+ + OCl^-$

b. The pH decreases (gets more acidic).

No.2

a. $HCl \rightarrow H^+ + Cl^-$
$HOCl \rightarrow H^+ + OCl^-$

b. When chlorine is added it becomes more acidic.

No.3

a. $HCl + e^- \rightarrow HCl^-$

$HOCl + e^- \rightarrow HOCl^-$

b. The pH gets more acidic.

No.4

a. $Cl_2\,(g) + H_2O_{(l)} \rightarrow H^+Cl^-\,(aq) + HO^- + Cl^-(aq)$

b. The pH drops below 7.

No.5

a. $Cl_2 + H_2O \rightarrow H^+Cl^-\,(aq) + H^+OCl^-(aq)$

b. The pH of the water in the swimming pool would go down.

no.6

a. $HCl\,(aq) \rightarrow H^+ + Cl^-$

$HOCl\,(aq) \rightarrow HO^+ + Cl^-$

b. No answer.

No.7

a. $HCl \rightarrow H^+ + Cl^-$

$HOCl \rightarrow OH^+ + Cl^-$

b. No answer.

No.8

a. $Cl_2\,(g) + H_2O \rightarrow H^+Cl^-(aq) + H^+OCl^-(aq)$

b. The water turns more acidic.

No.9

a. $Cl_2\,(g) + H_2O\,(l) \rightarrow H^+Cl^-(aq) + H^+OCl^-(aq)$

b. The pH of the water goes down.

No.10

a. $Cl^- + H_2{}^+O^{2-}\,(l) \rightarrow H^+Cl^-(aq)$

b. The pH will increase because chlorine is an alkali.

No.11

a. no answer.

b. The pH will decreases when the water is chlorinated.

No.12

a. $HCl \rightarrow H^+ + Cl^-$

$HOCl \rightarrow H^+ + OCl^-$

b. pH would decrease towards pH 7.

No.13

$HOCl \rightarrow H^+ + OCl^-$

b. The pH would increase because of the positive hydrogen ions.

No.14

a. $HCl\,(aq) \rightarrow H^+ + Cl^-$

$HOCl(aq) \rightarrow H^+ + OCl^-$

b. The pH will be lowered from 7(pH of water) to an acid pH (due to fromation of acid)

No.15

a. $HCl \rightarrow H^+ + Cl^-$

$HOCl \rightarrow H^+ + OCl^-$

b. The pH gets lower when chlorine is added.

No.16

a. $HCl \rightarrow H^+ + Cl^-$

$HOCl \rightarrow H^+ + OCl^-$

b. The pH level decreases to become more acidic.

No.17

a. $HCl \rightarrow H^+ + Cl^-$

$HOCl \rightarrow H^+ + OCl^-$

b. The pH drops(it because acidic), goes towards 0.

Part 3

No.1

a.pH > 7

b. pH =5

c. no answer.

d. 5

e. no answer.

f. The pH vlue was too low causing the HOCl to react and form irritating compounds.

No.2

a.pH > 7

b. low pH values.

c. came form nitrogen chloride.

d. pH =5.5

e. about pH 5.

f. The pH was too high and didn't kill the bacteria.

No.3

a.pH 5.5

b. pH 6

c. nitrogen compounds from the air.

d. pH 5--6.

e. pH 5.5

f. The pH value was too low and the HOCl has reacted with the nitrogen compounds.

No.4

a.pH 7

b. pH 9

c. nitrogen react with chlorine.

d. pH 10

e. pH 8

f. nitrogen has reacted with the chlorine causing compounds to form which cause sore eyes because the pH of the water has been too low because of too much chlorine.

No.5

a.pH 7

b. pH 10

c. The air.

d. pH 5.5

e. The average is 7.5 **(5.5+7+22.5) / 3 =7.5

f. The pH has dropped to cause bacteria in the pool and nitrogen compounds which cause sore eyes.

No.6

a.pH 7 is best

b. no answer.

c. They are formed in the chemical reaction.

d. pH 5.5

e. pH 8.5

f. The % of chlorine was too high.

No.7

a.The pH has roughly got to be in the middle about pH 5.

b. About pH 8 not too high because it won't make but too low it will make the bad nitrogen .

c. from the human body, eg. urine.

d. somewhere in the middle 5--7

e. 5--6

f. The pH was too low and the bad smelly compounds were made.

No.8

a.pH 5.5

b. pH 8

c. The air.
d. pH 5
e. pH 6
f. The chlorine is to acidic the pH is too low.

No.9
a.
b. pH 1
c. the nitrogen in the air joined with the Cl in HOCl (aq).
d. pH 5
e. somewhere between pH 5 and pH 6.
f. The HOCl (aq) reacted with the nitrogen in the air to give a substance with the N-Cl bond. That give them sore eyes. The pH was too low.

No.10
a.pH 7, because acid aould be harmful.
b. pH 10, because it is a low pt on the graph.
c. the nitrogen comes off of us in the water.
d. pH 5
e. pH 7
f. The water was at a low pH and the hypochlorous reacted with the chlorine and it was an irritant.

No.11
a.pH 6
b. pH 6
c. The nitrogen compounds come fromour bodies-sweat, hair, skin etc.
d. pH 4.6
e. pH 6
f. The pH of the water was too low, the nitrogen reacted with the acid hypochlorous.

No.12
a.pH 7
b. the best pH values to avoid nitrogen formation is pH 7 onwards.
c. bacteria
d. pH 5
e. pH 6
f. The pH values in the pool dropped to low to allow nitrogen compounds to form.

No.13
a.pH 5.5
b. pH 9.5
c. HOCl
d. pH 5
e. pH 3
f. The pH was too low.

No.14
a. pH 5.5
b. between 6 and 6.5
c. They come from the air, inside the pool (as air is 70% nitrogen).
d. beween 7.5 and 8
e. pH 6.
f. The pH ws too low, the HOCl reacted with nitrogen to form the compounds which cause eye-soeness.

No.15
a. pH 5
b. pH 5
c. no answer.
d. pH 6
e. pH 5
f. Too much chlorine has been added it has too much acid.

No.16
a. pH 4
b. pH 6
c. The air.
d. pH 1.5
e. pH 4
f. The pH level was too low.

No.17
a. pH 5.5
b. pH 10
c. substances in your eyes that form with Cl plus H2O.
d. pH1.2
e. ph 5.5
f. The pH is too low (acidic).

Unit 15 Trees and Cars

No.1
Hint 2.

When 1 mole C_8H_{18} is burned, 8 moles of CO2 is produced. This gives a ratio of C_8H_{18}: CO_2 = 1:3.
42000 km / 10 km = 4200 (l)
$C_8H_{18} + O_2 \rightarrow 9H_2O + 8\ CO_2$
$2\ C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 9\ H_2O$
1 mole C_8H_{18} → 8 mole CO_2
114g 352g

got the ratio is 1: 3

700g x 3 = 2100, 2100 X 4200 = 8820000, 8820kg / 6 = 133.2 tree

No.2
Hint 5.

Petrol C_8H_{18}, mass = 114g
$2\ C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 9\ H_2O$
114 → ?
228 → 16 x 44 =704

ratio is 1 : 3

so 700 2100

$\frac{L}{l} = \frac{mass}{700g}$ therefore 2100 / 700 = 3 litres

$\frac{m}{700} \rightarrow \frac{distance}{10km}$

$\frac{2100}{700} \rightarrow \frac{d}{10}$ therefore distance = 30 km

because 2.1 kg → 30 km
so 6 kg → 90 km

after got hint, 42000 / 10 = volume =4200
4200 x 700 x 3= 9000,000g

No.3
Hint 4.

The car produces 16800kg of carbon dioxide and a tree only takes in 6 kg of carbon dioxide, so we need a lot more trees to offset the pollution produced by just the one car.
$C_8H_{18} + 12\ 1/2O_2 \rightarrow 8\ CO_2 + 9\ H_2O$
114g 432g

ratio 1 : 3
12400g → 37400g

so 1 kg → 4 kg

4200 16800 kg

No.4
Hint 2, 4, 5.

C_8H_{18} = 114g   42000/ 10 =4200 (litres)
2 C_8H_{18} + $25O_2$ → $16CO_2$ + 9 H_2O
2 moles   25moles 16 moles
228g   684g
1g   3g

700 g   2100 g--from 1 litre of petrol

4200 litres   12600 litres--per year

(they stick here)

4200 X 700 = 29400

700 x 3 x 4200 = 9,000,000g = 9,000 kg   9000 / 6 =1500 g

No.5
No hint

42000 / 10 = 4200 (litres)
4200 X 0.7 = 2940 kg

2 C_8H_{18} + $25O_2$ → $16CO_2$ + 9 H_2O
1 mole   8 mole
114 g   352 g

ratio 1 : 3

so   2940 X3 = 8800 kg of CO_2
Therefore you need 8800 / 6 = 1466 trees, the quotation from the newspaper is incorrect.

No.6
Hint 2.

The quotation from the newspaper is false, it should be approximately 1400 trees use up about 8000 kg of carbon dioxide per year which is equivalent to a car driving 42000 km.
C_8H_{18} + 12 1/2O_2 → 8 CO_2 + 9 H_2O
1 mole → 8 mole
114g → 352 g
1 g → 3 g
700 g   2100 g

4200 X 2100 = 8000,000 g =8,000 kg so 8000/ 6 =1400 trees

No.7
Hint 2, 3. (this group work very slowly, needed more help)

42000 / 10 = 4200 litres of petrol
C_8H_{18} + 12 1/2O_2 → 8 CO_2 + 9 H_2O
1 mole gives 8 moles
114 g   352 g
1 g   3 g

1 litre octane   2100 g CO_2
4200 X 2100 g = 8500 kg

No.8
No hint.

C_8H_{18} + 17 / 2 O_2 → 8 CO_2 + 9 H_2O

because 10 km → 1 litre
1 km 1/ 10 litre
42000 km 4200 ltres

4200 x 0.7 = 2940 kg = 2,940,000g

C_8H_{18} =114 g 2940000 x 8 x 44 /114 = 9,077,900 g =9077.9 kg

No.9
No hint.

4200 litres petrol used
C_8H_{18} + 12 1/2 O_2 → 8 CO_2 + 9 H_2O
1 mole 8 mole
114 g 352 g

4200 X0.7=2940 (352 / 114) X 2940 = 9000 kg
so newspaper is wrong.

No.10
The given hint is "use formula weight ". (they seem have a plan?)
1. Find he balanced equation for the combustion of octane, find the gram formula mass of octane and carbon dioxide.
2. Work out the mass of octane used in 42000 km, from this answer and the gram formula mass of carbon dioxide you can work out the mass of carbon dioxide used.
3. The actual mass of carbon dioxide used was a lot more than the value stated in the newspaper.

C_8H_{18} + 25 / 2 O_2 → 8 CO_2 + 9 H_2O
because 1 litre = 10 km
42000 km = 4200 litres
so 4200 litres = 4200 X 700 = 2,940,000 g = 2940 kg

114 g 352 g

1 g 352 / 114

2940 X352/ 114 = 9000 kg

No.11
Hint 7.

Work out the equation of combustion for octane, make out rough ratios octane burning into CO_2 produced, calculated the amount of litres and then calculated the weight of the octane.
Then the 1: 3 ratio used to calculate the amount of CO_2 produced to get the answer.

C_8H_{18} + 25 / 2 O_2 → 8 CO_2 + 9 H_2O
114 352
1 mole 3 mole

octane : CO_2 ratio is 1: 3
4200 x 700 g = 2940 kg, octane = 2 kg

Unit 16 Bonding

No.1

(1) We must measure electrical conductivity as melt which will cost £40 and test reaction with water costing an extra £30 although.

Extra Q: dissolve in water, measure electrical conductivity as dissolved, measure melting pont. It comes to £90.

If dissolves means either polar covalent or ionic. If melting point high it is ionic. If melting point is low, it is polar covalent.

No.2

(1) A-measuer melting point
C-measure solubility
E-measure electrical conductivity as melt; total £100.

(2) No bonding

No.3

-1) D-measure electriacl conducility as dissolved,
E-measure electrical conductivity as melt
C-solubility; total is £100.

(2) No bonding

No.4

(1) D-measure electrical conductivity as dissolved.
E-measure electrical conductivity as melt.
A-measure melting point.

(2) No bonding

No.5

(1) Type of bonding: <u>covalent.</u>
(Aluminum + hydrochloric acid → aluminum chloride + hydrogen)

(2) Money spent: A-measure melting point £30
B-measure boiling point £20
C-measure solubility £30

No.6

(1) B-measure boiling point
C-measure solubility
D-measure electrical conductivity as dissolved

(2) No bonding

No.7

(1) D-measure electrical conductivity as dissolved £30.
B-measure boiling point £20.
E-measure electrical conductivity as melt £40.

(2) No bonding

No.8

(1) E-measure electrical conductivity as melt.
A-measure melting point.
B-measure boiling point.

(2) No bonding

No.9

(1) A, D, F.

(2) Polar covalent.

No.10

(1) A-measure melting point.
C-measure solubility.
E-measure electrical conductivity as melt.

(2) The results of the experiments show us that $AlCl_3$ is <u>ionic</u>.

No.11

(1) A-measure melting point.
F-reaction with water.
C-measure solubility.

(2) The type of bonding is ionic.

No.12

(1) The type of bonding being referred to is ionic bonding.

(2) We wish to buy E-measure electrical conductivity as melt.

No.13

(1) A-measure melting point.
E-measure electrical conductivity as melt.
C-measure solubility.

(2) It is a covalent bond.

No.14

(1) E-measure electrical conductivity as melt.
A-measure melting point.
B-measure boiling point.

(2) If it doesn't conduct it would be poor which would be covalent or polar covalent.
If it doesn't melt it would be high, so polar covalent, ionic or metallic.
If it sublimes it would high so covalent ionic or metallic.

T he result is covalent.

No.15

(1) Our budget was £ 90, we used tests = A, C, D.

(2) We think it is ionic because $AlCl_3$ is very soluble and ionic compounds are often soluble. $AlCl_3$ also does not melt and ionic compounds have a high melting point. It is only ionic and covalent bonds that have these similar properties, so we done the electrical conductivity as dissolved and the results showed it was an ionic bond.

No.16

(1) Aluminium chloride contains ionic bonds.

(2) We reached this conclusion by buying the following 3 tests results: A, C, D.
We found out that $AlCl_3$ does not melt but turns from solid to gas at 193 °c and it is extremely soluble we elimanated. The other types of bonding by using the above information.

No.17

(1) After some research we conclude that $AlCl_3$ has polar covalent bonding.

(2) It conducts good when it's dissolved in water and does not melt, also from the information that it dissolves it must be soluble.

No.18

(1) We choose the following three experiments, measuring melting point, measuring solubility and measuring electrical conductivity as melt because only two choices for it, but by using our result we found out that it couldn't melt but by doing these we found the boiling point is extremely high but by going through the result .

(2) We found that it is covalent.

No.19

(1) After discussing in the group we have come up with the folowing conclusion using " test D" measuring conductivity as a solution. The solution conducted very well. This ruled out covalent bonding then using " test A" measuring melting point.

(2) The solution didn't melt, therefore this ruled out polar covalent.

(3) Finally, using experiment C "measure solubility" the result of this was the solution was extremely soluble, this ruled out metallic bonding.

(4) So we conclude after these three experiments the solution must be ionically bonded.

(5) The total cost of the experiement was£90: A=£30, C=£30, D=£30.

No.20

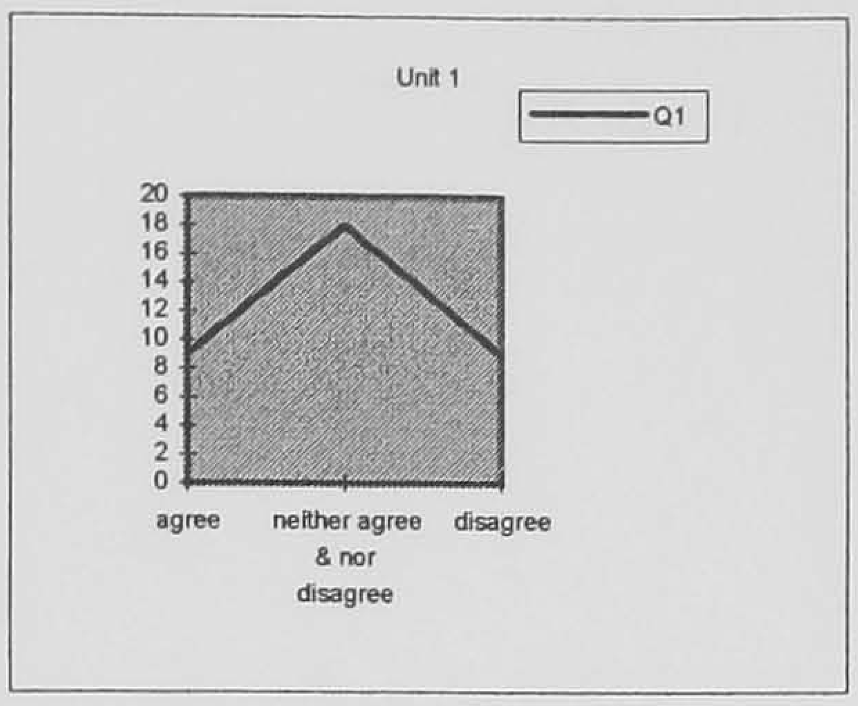
(1) A-measure melting point £30
C-measure solubility £30
E-measure electrical conductivity as melt £40.

(2) No bonding

Appendix G

The Graph of Response to Thirteen Fixed Questions

Unit 1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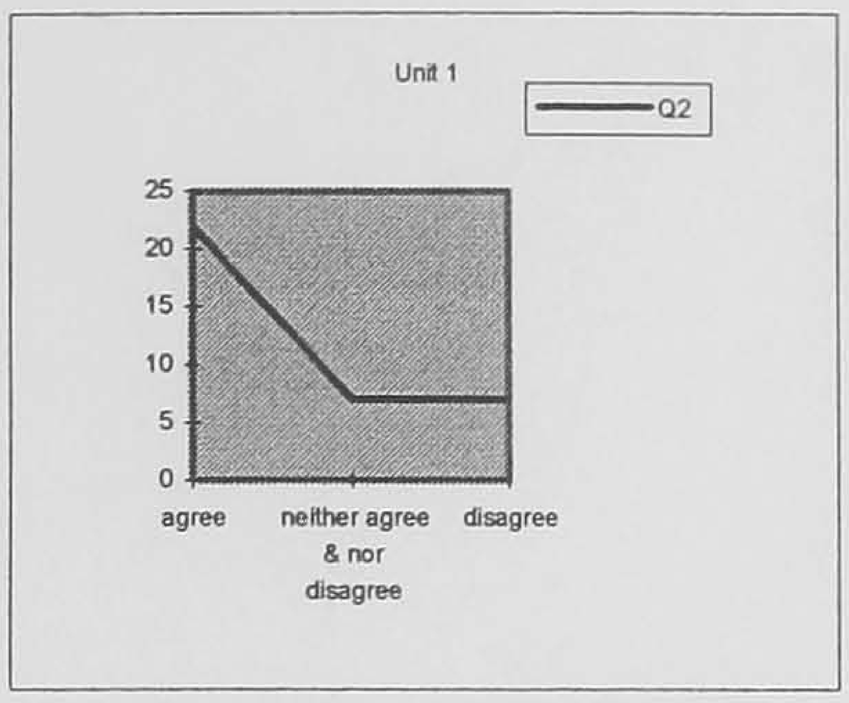
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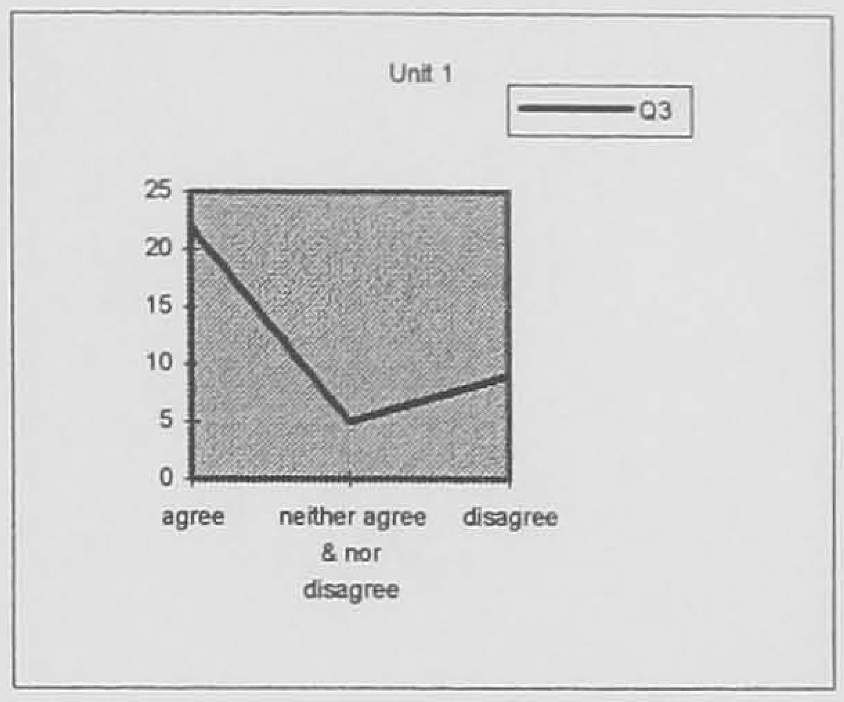
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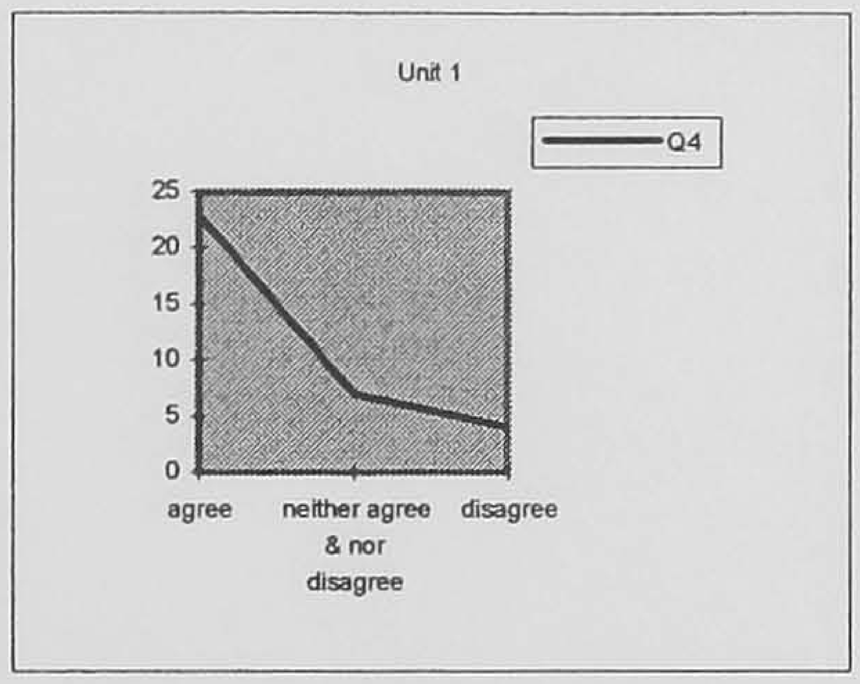
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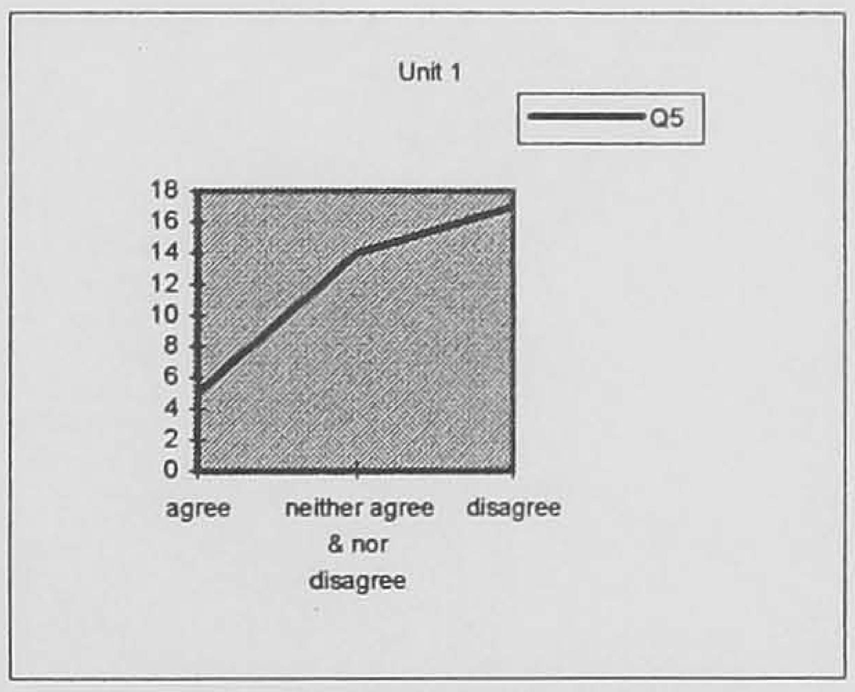
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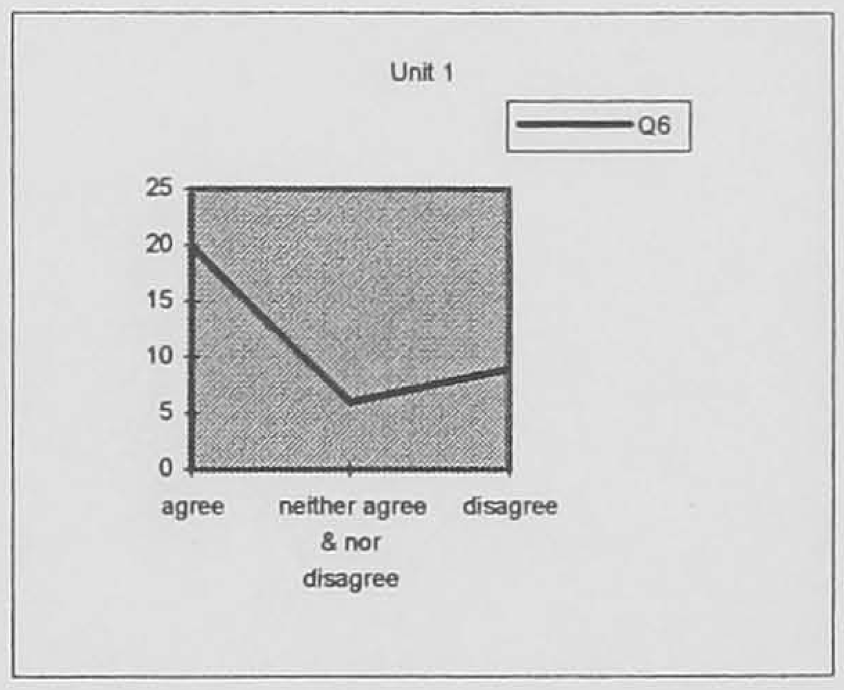
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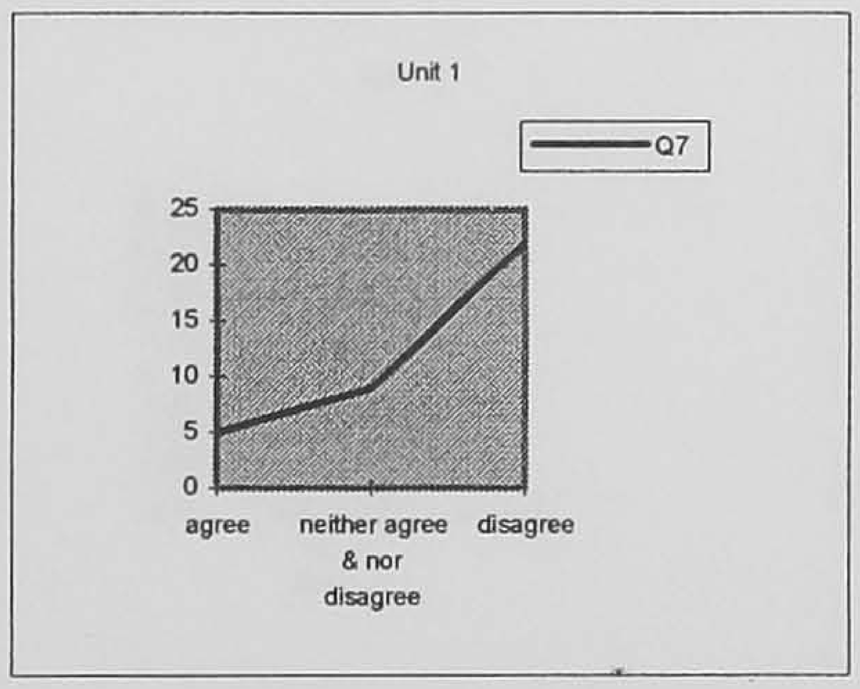
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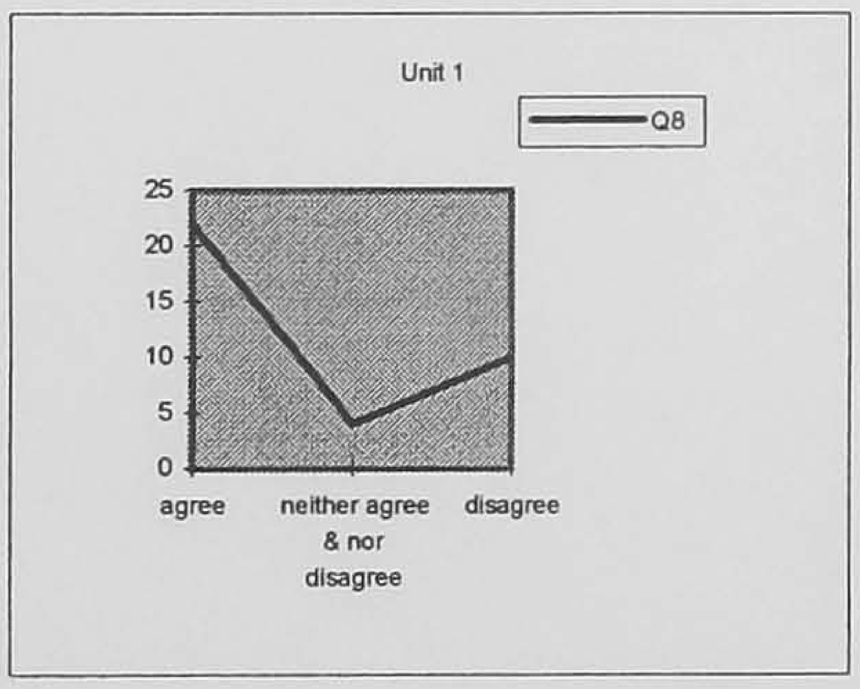
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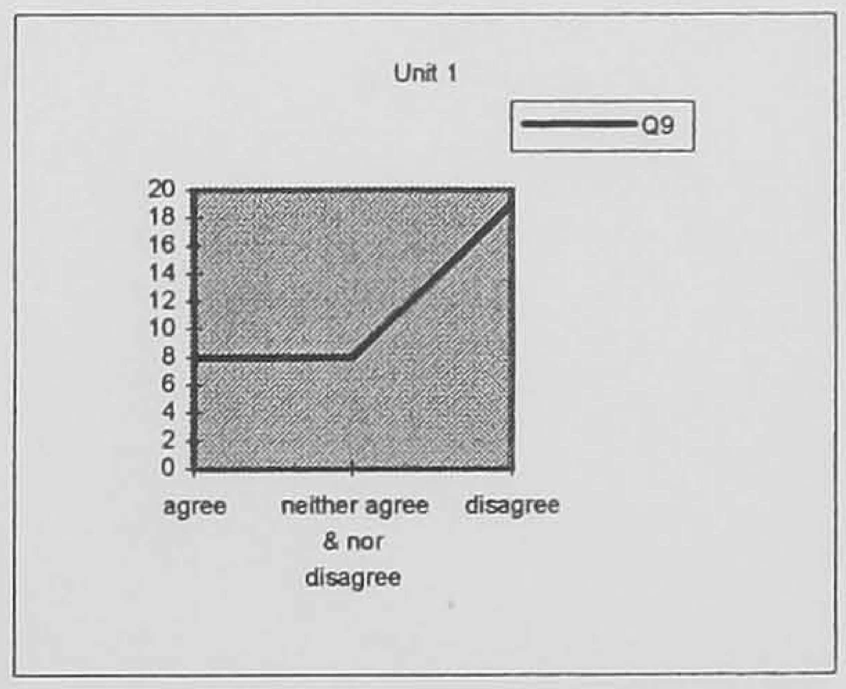
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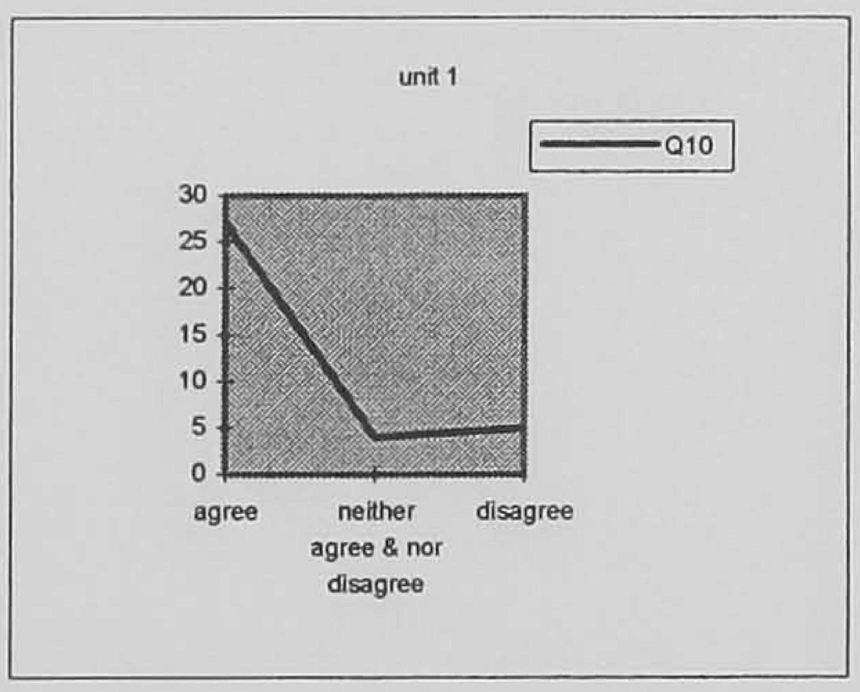
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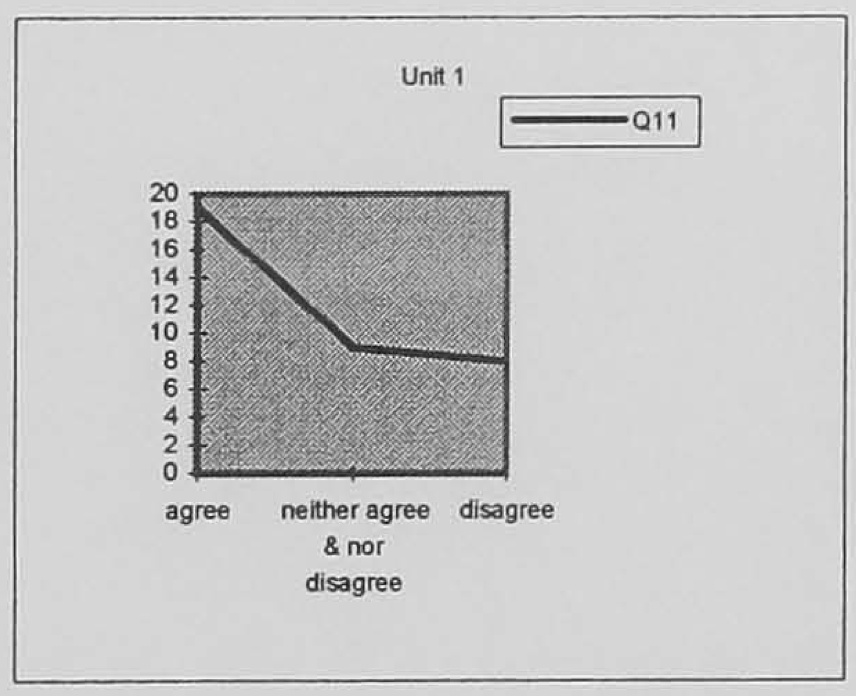
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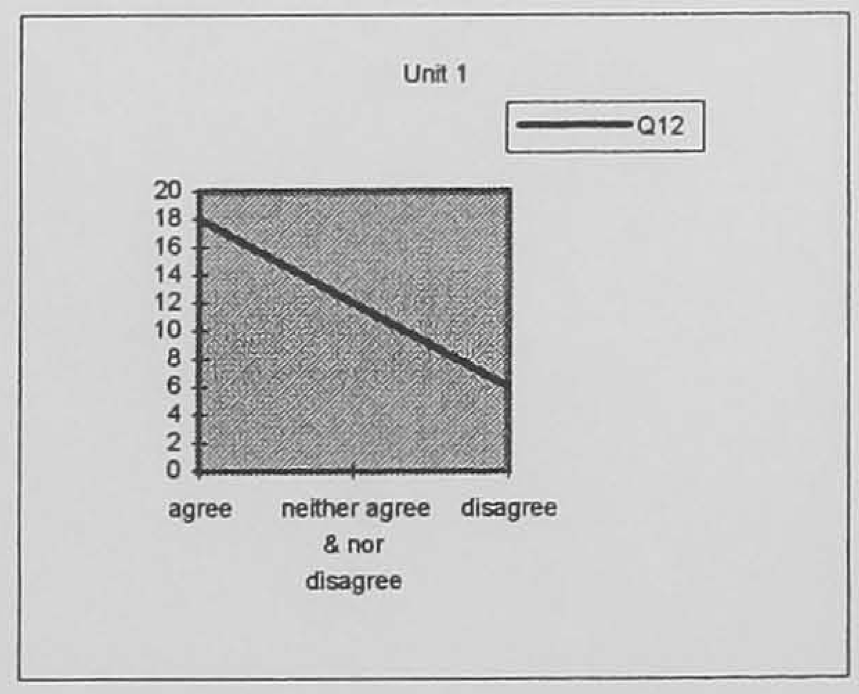
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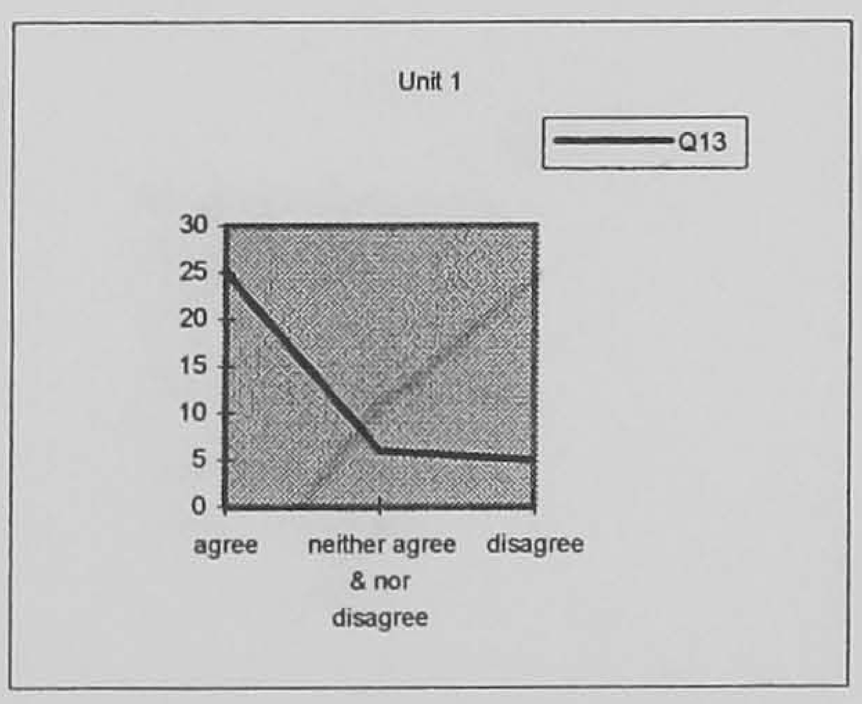
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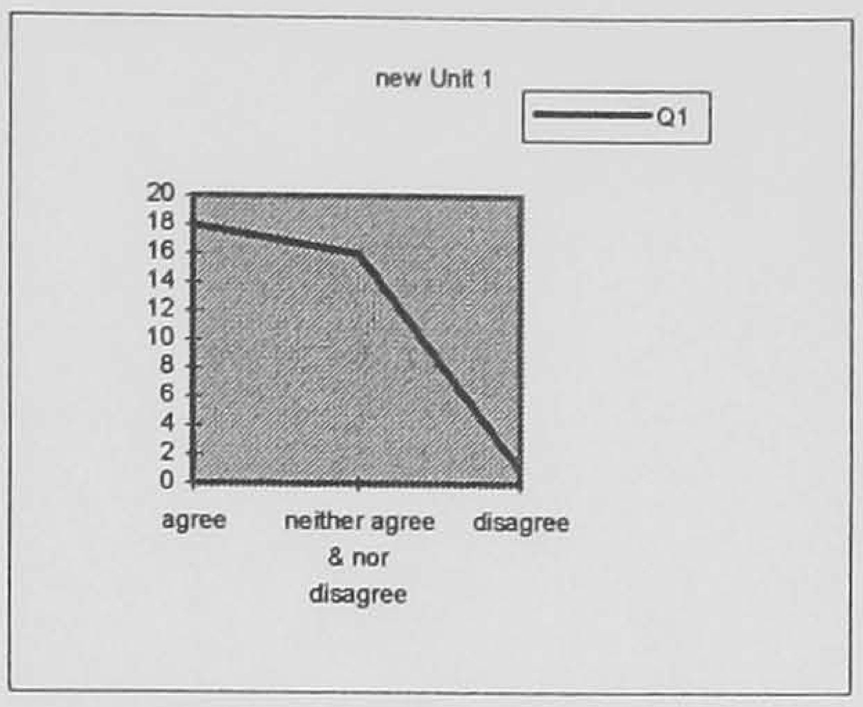
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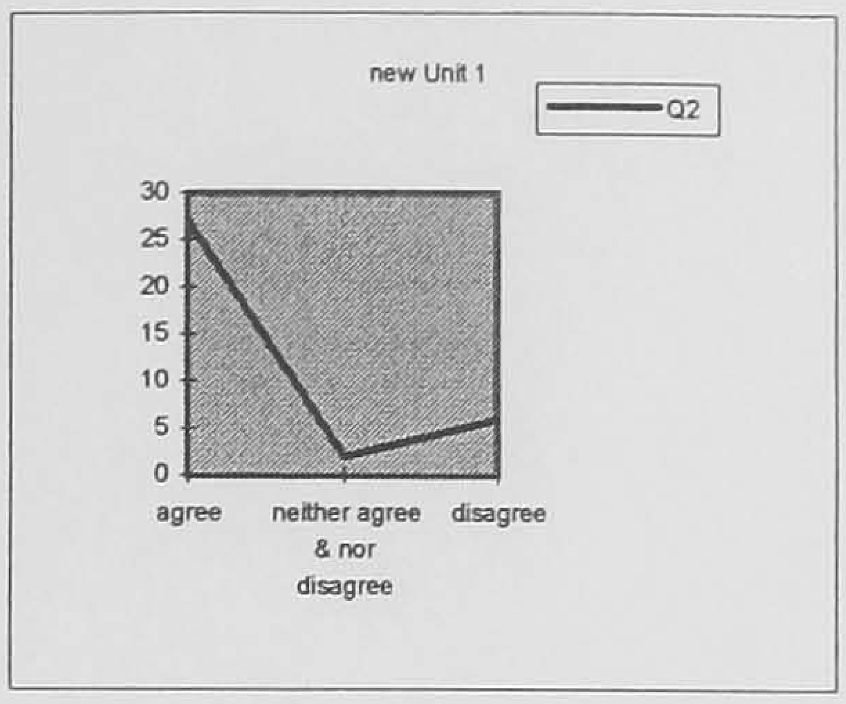
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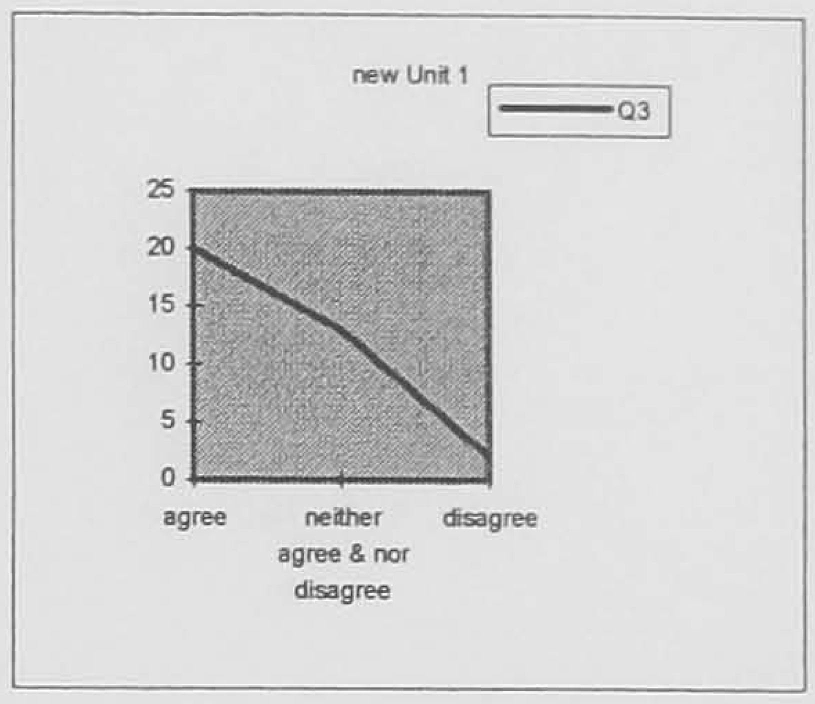
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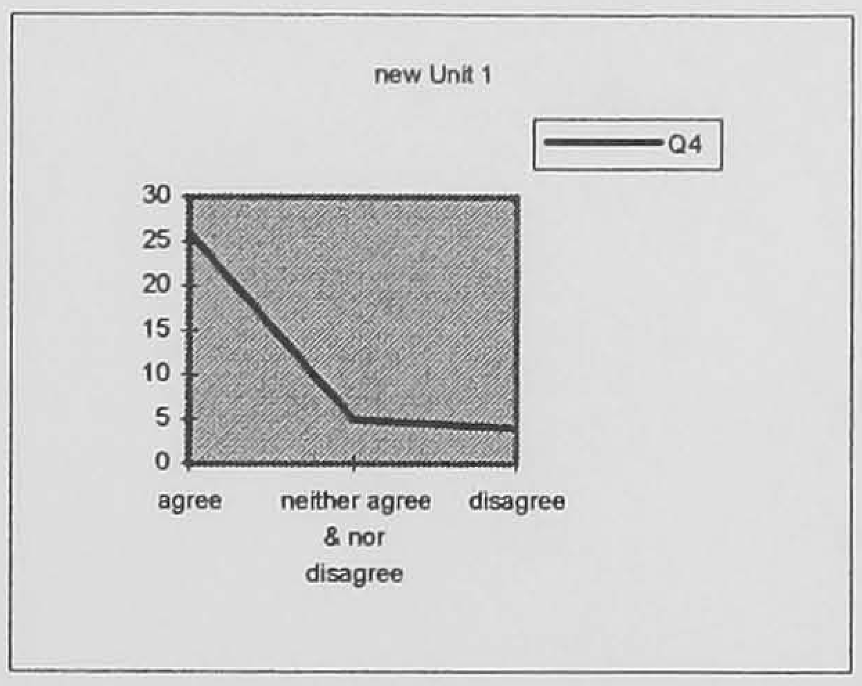
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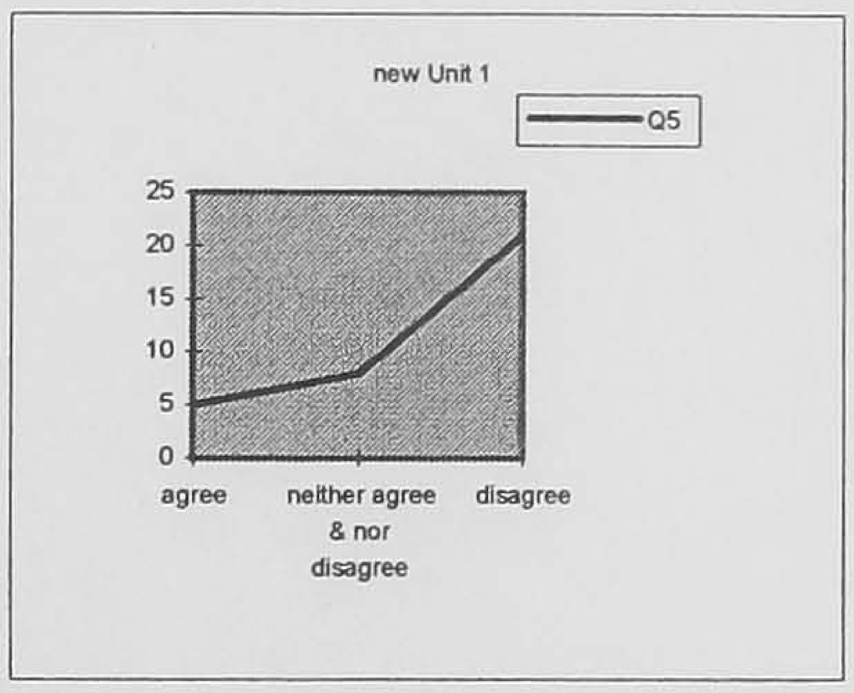
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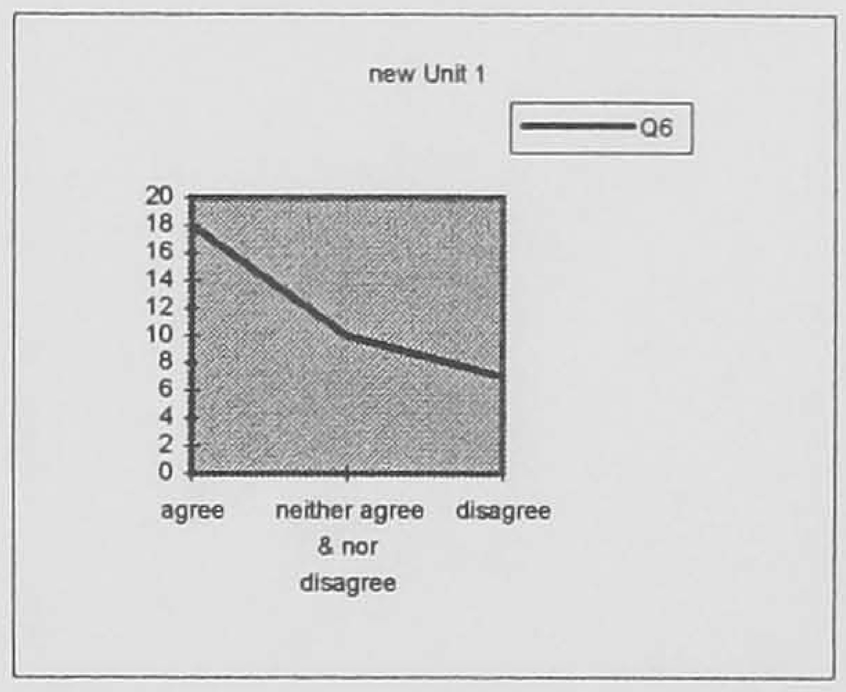
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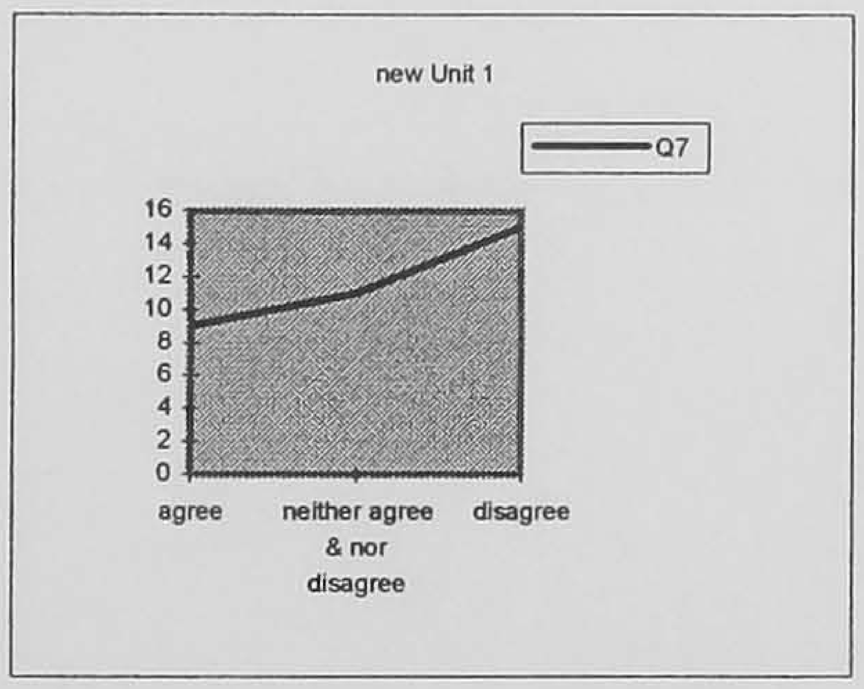
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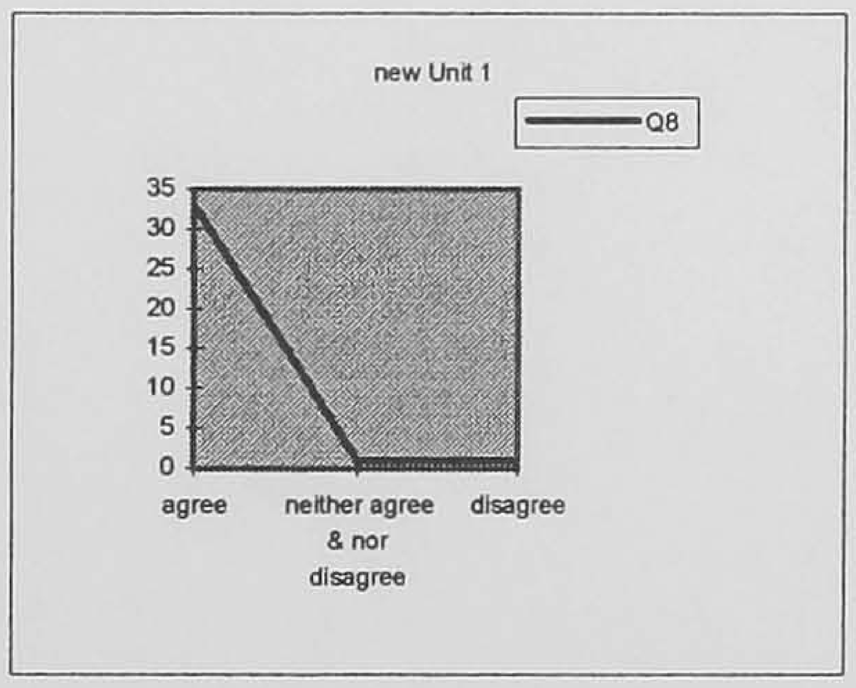
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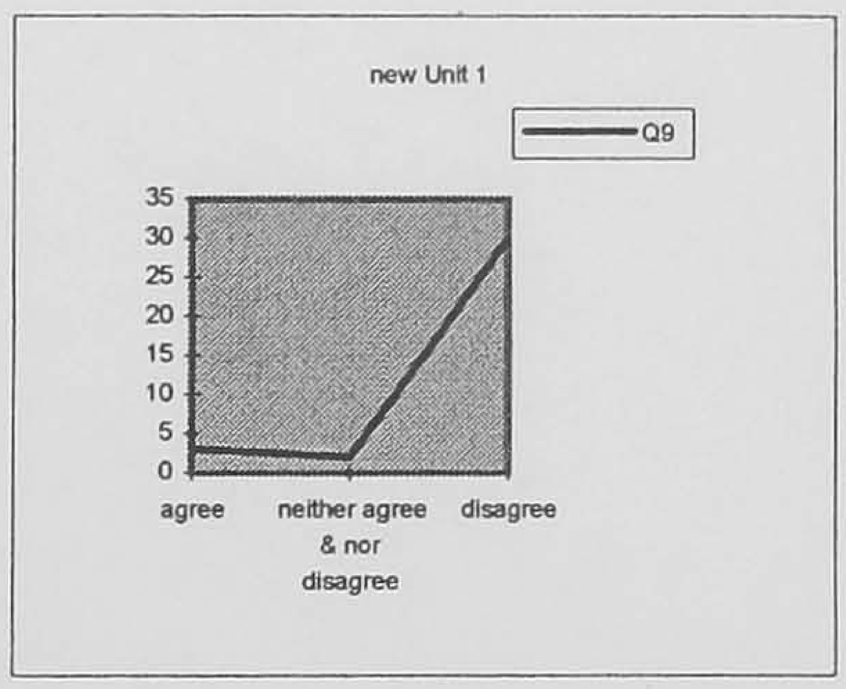
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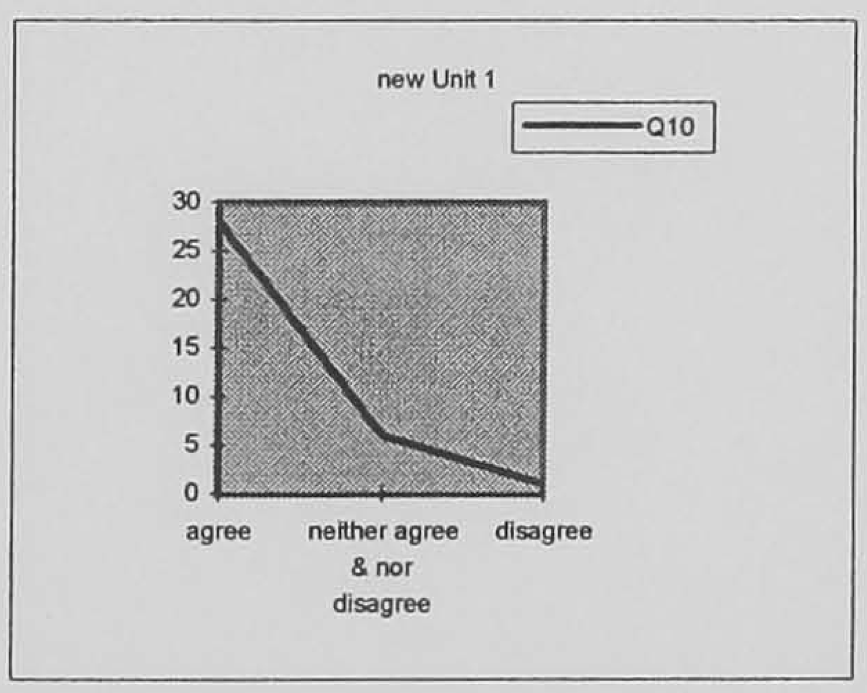
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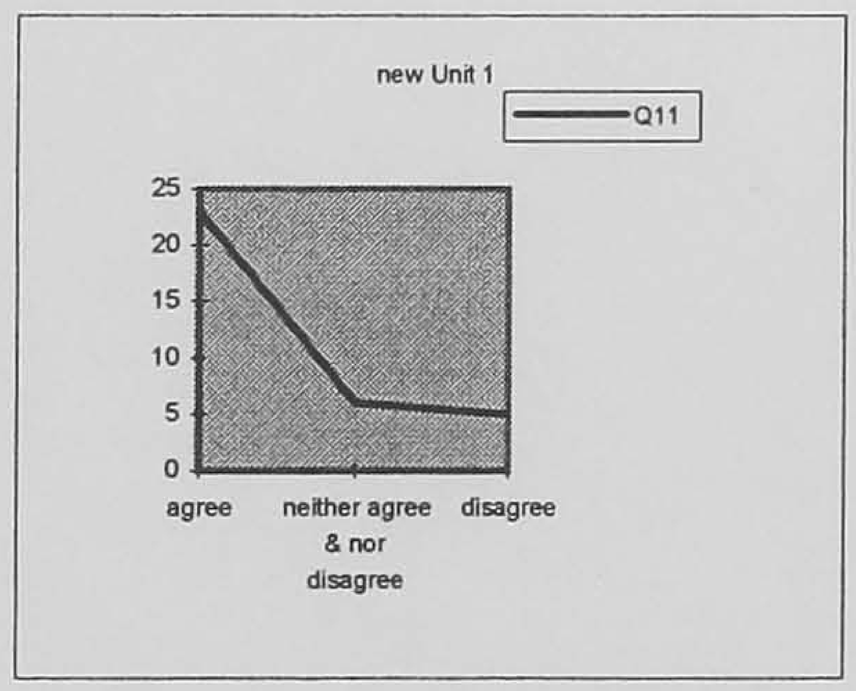
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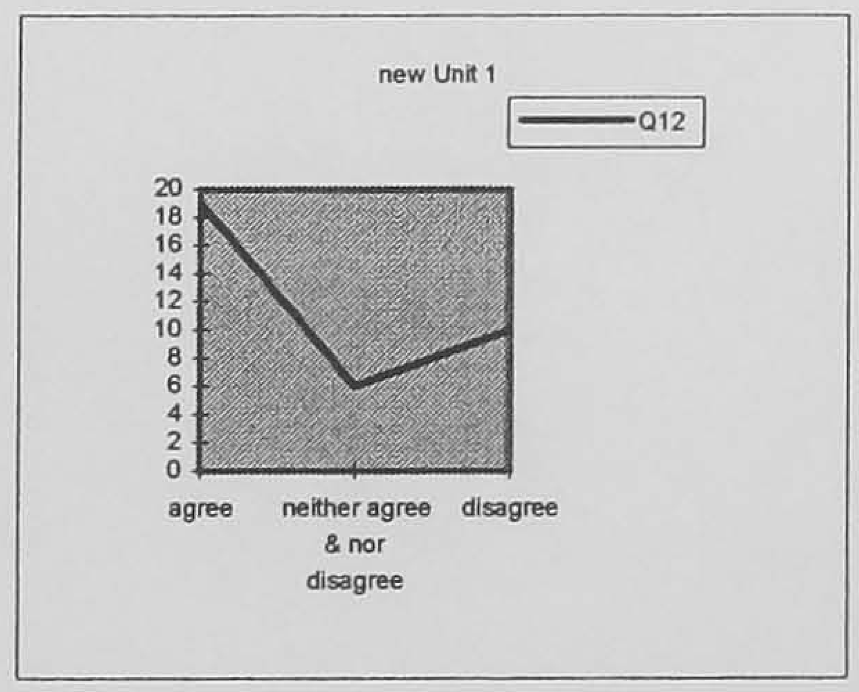
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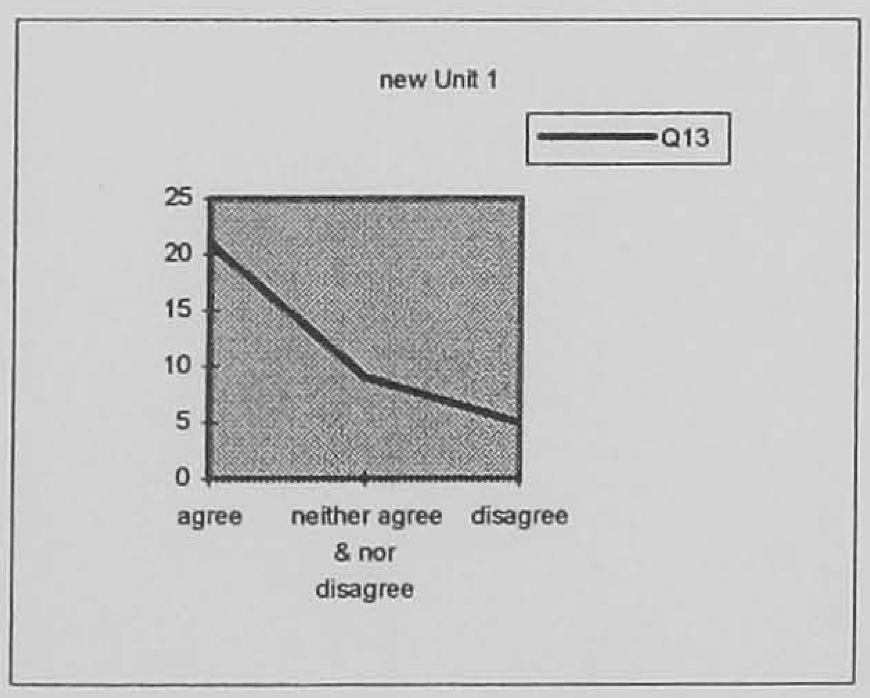
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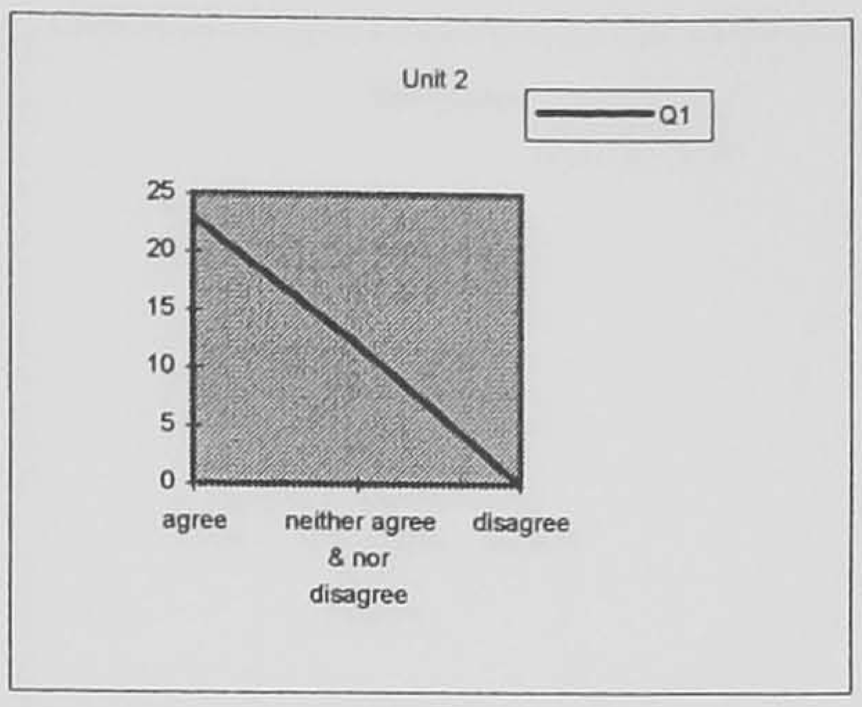
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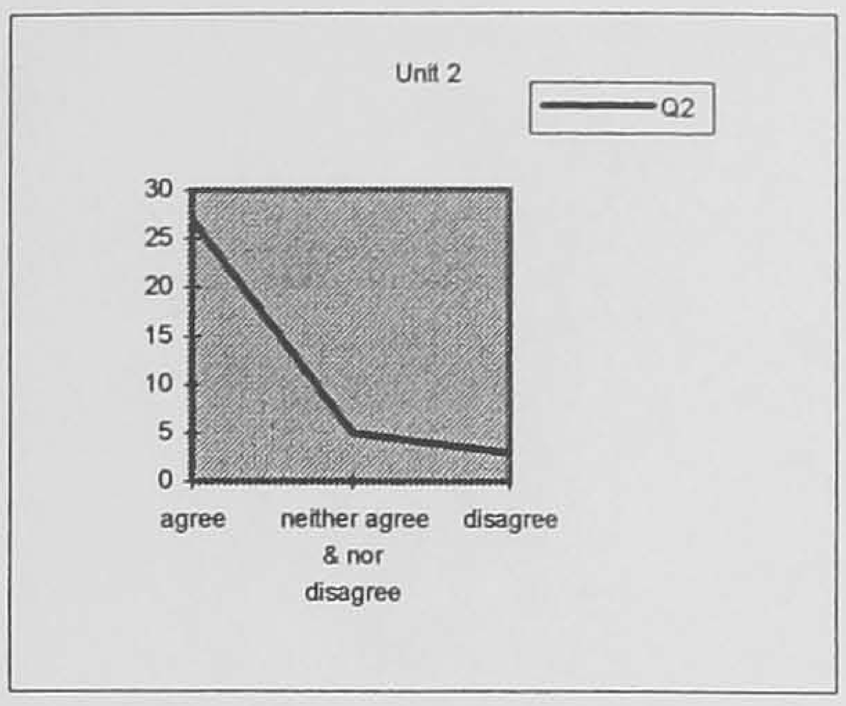
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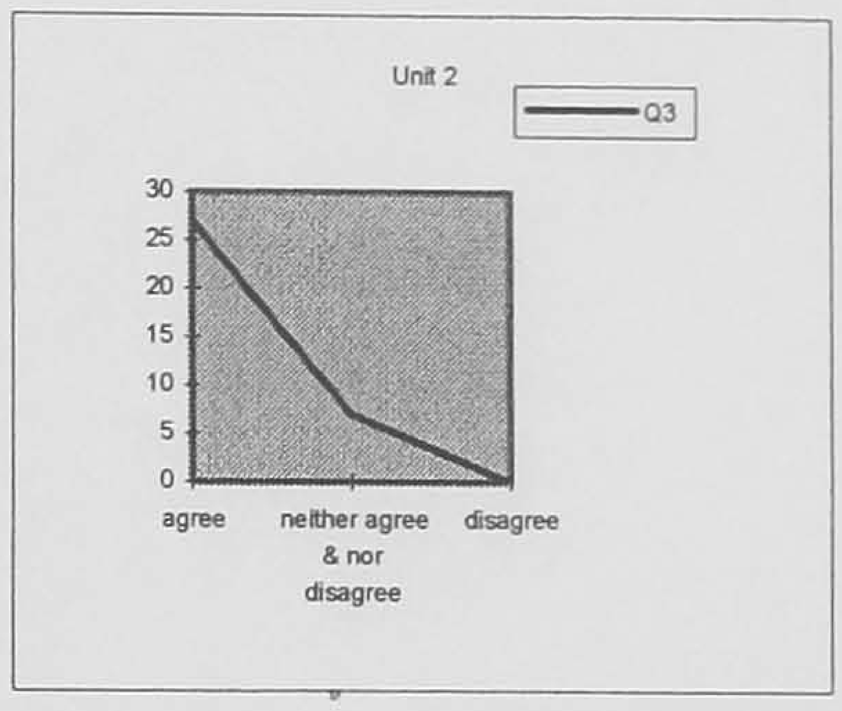
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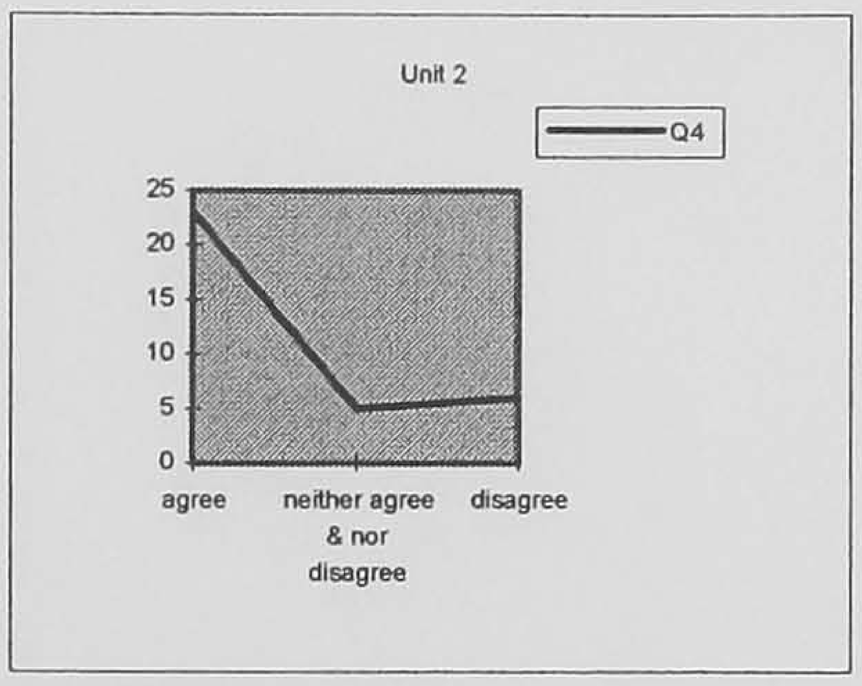
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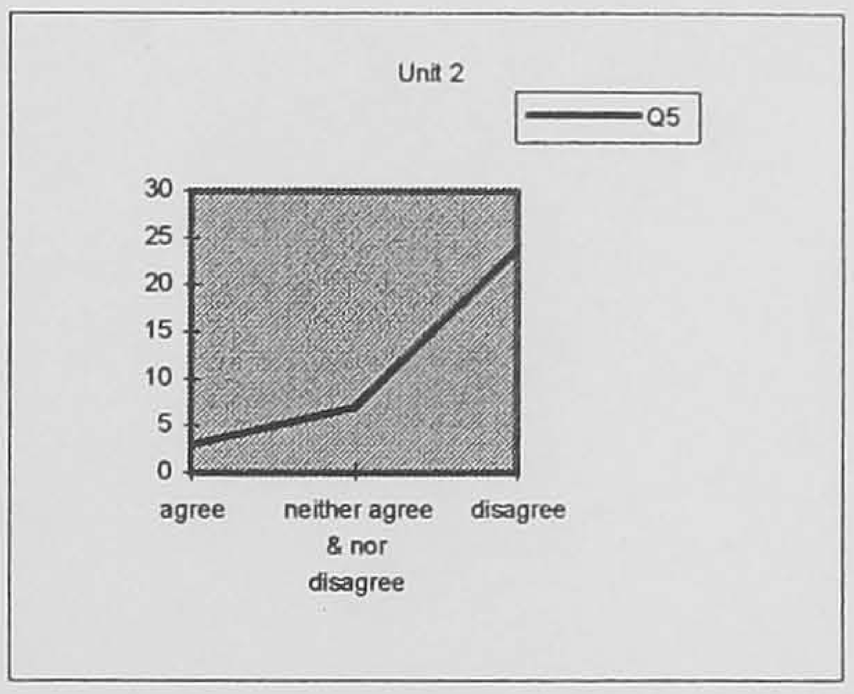
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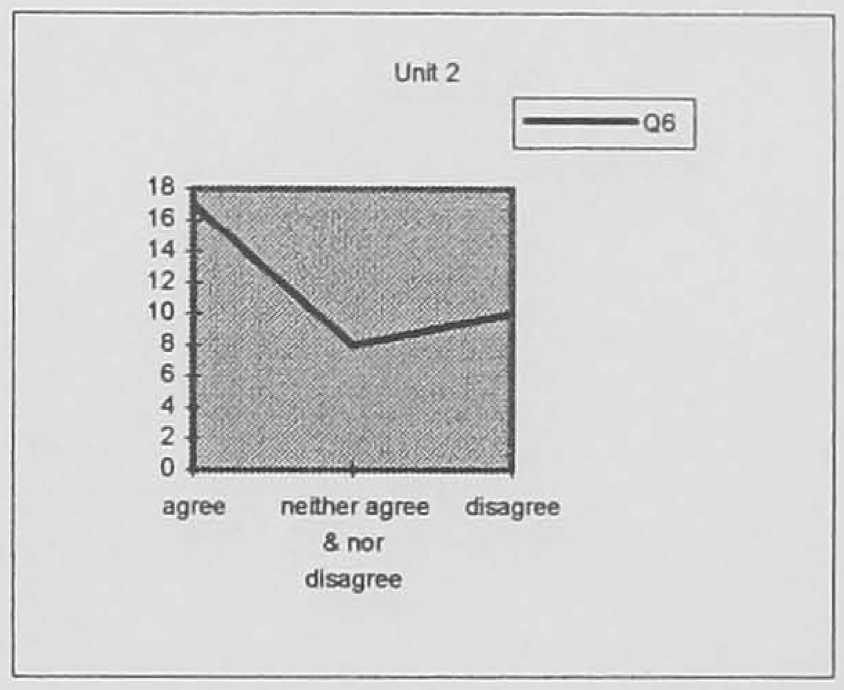
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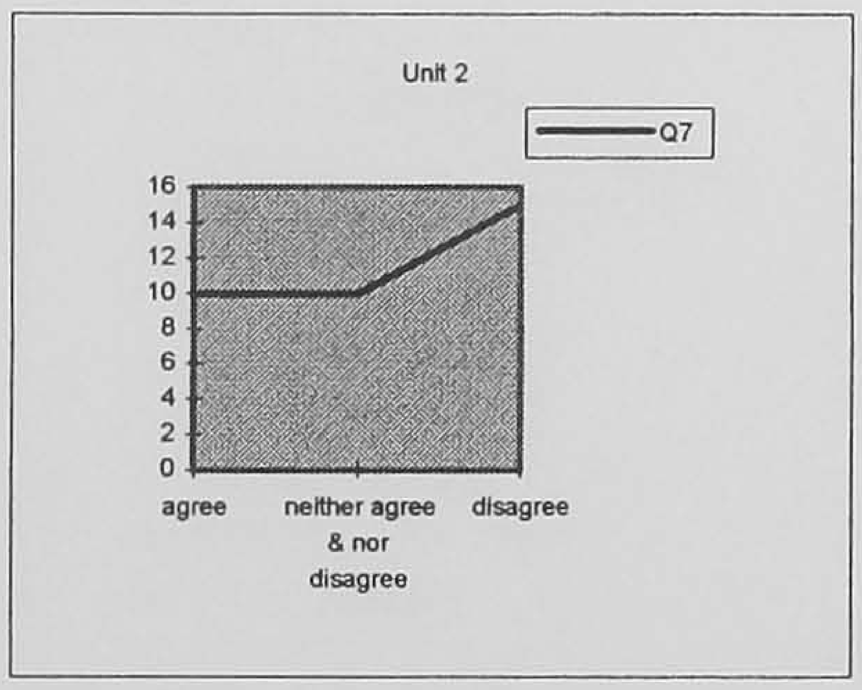
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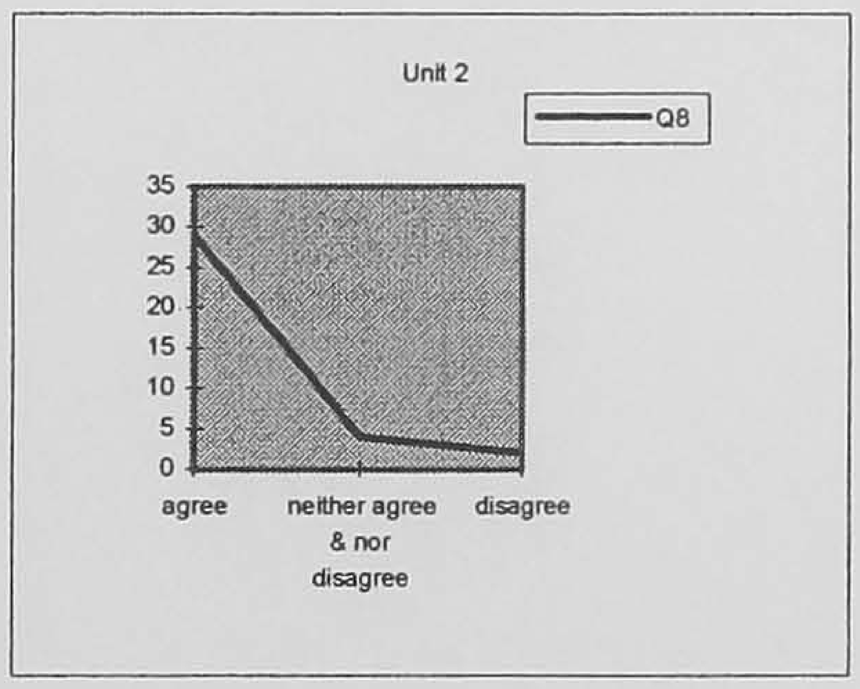
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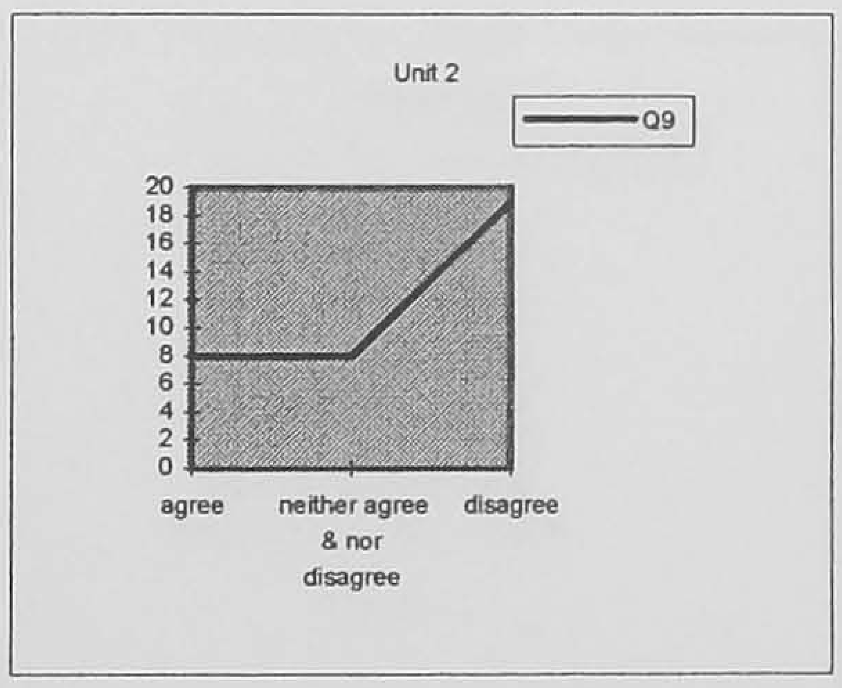
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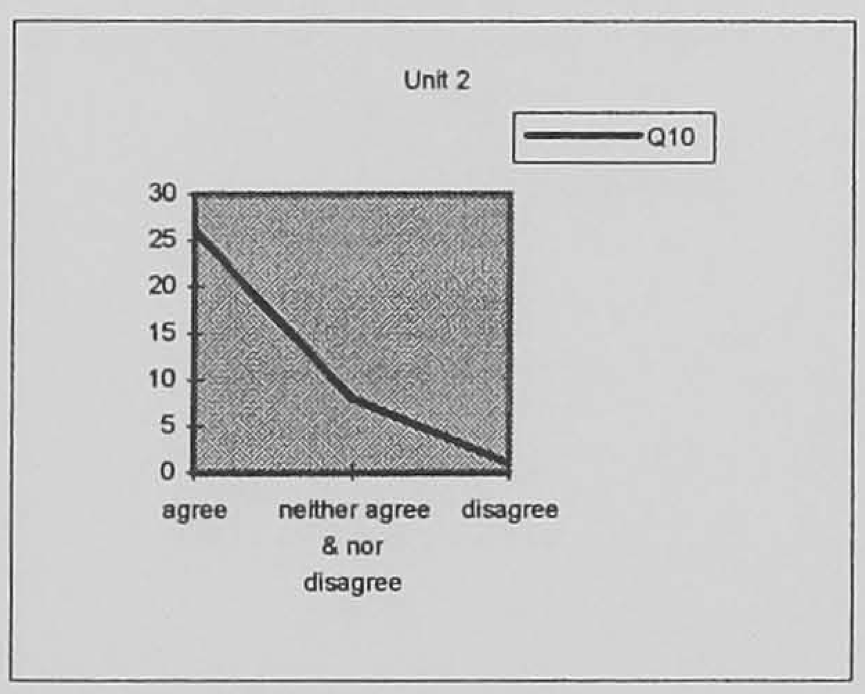
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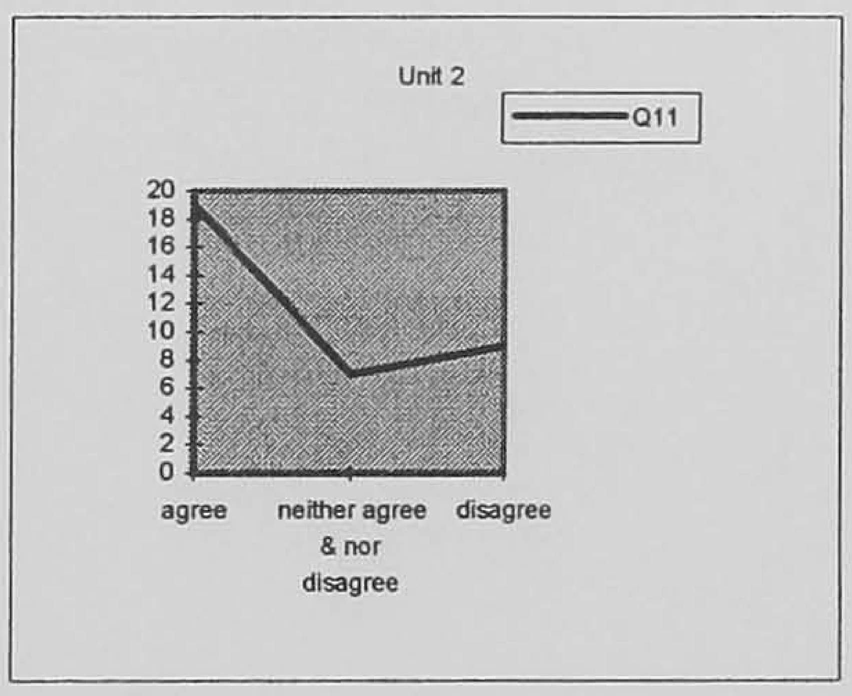
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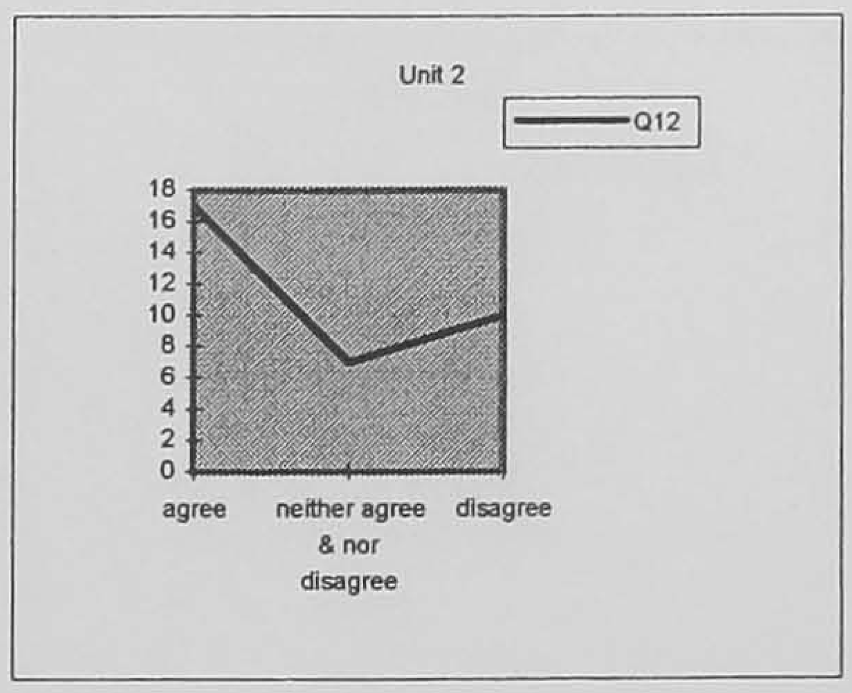
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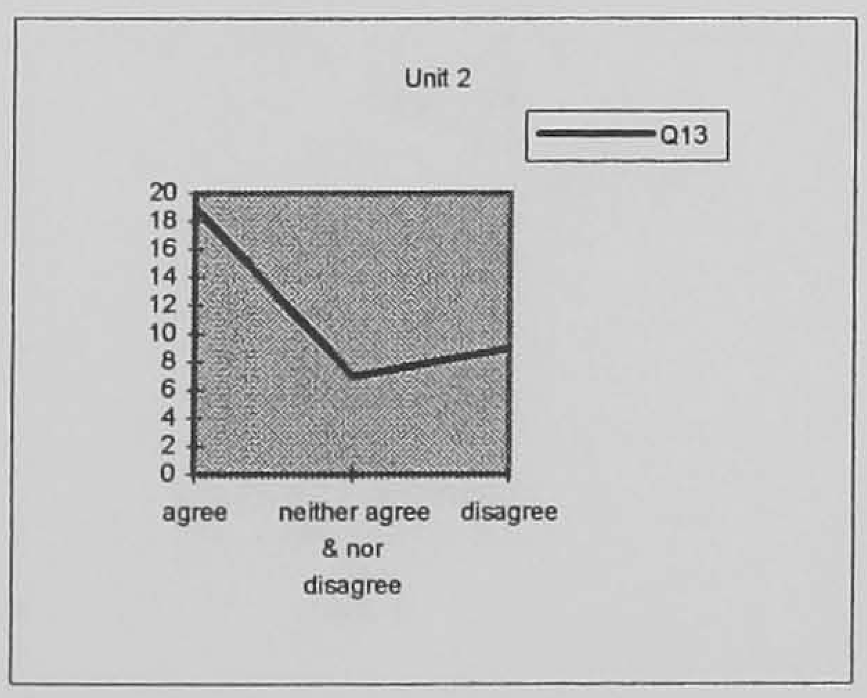
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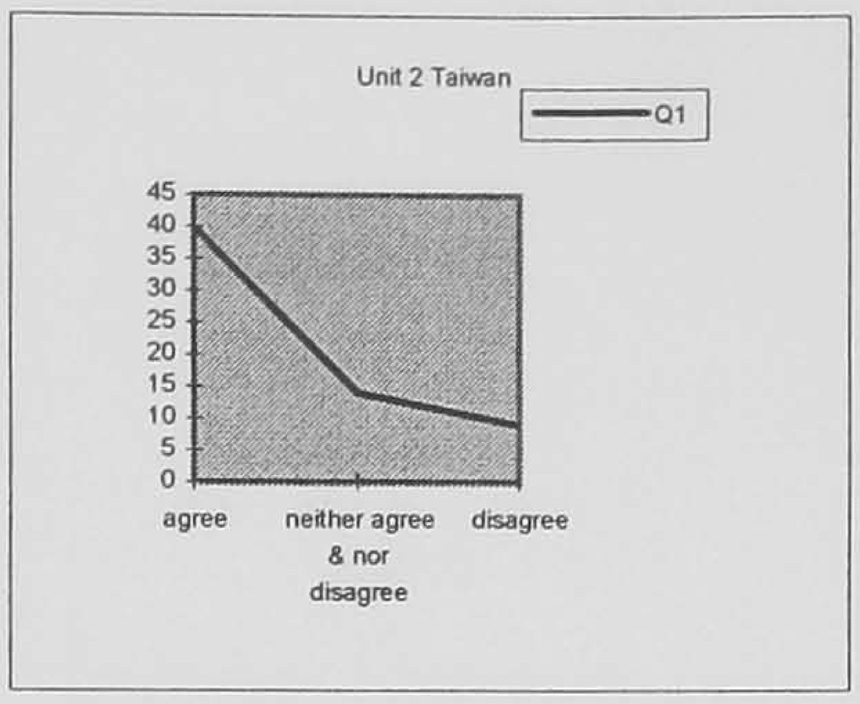
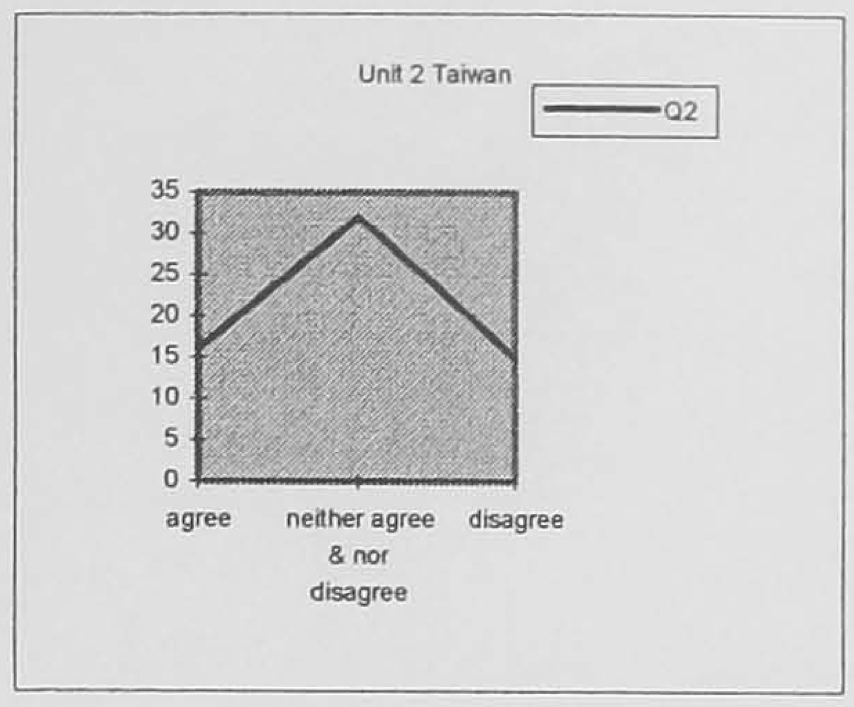
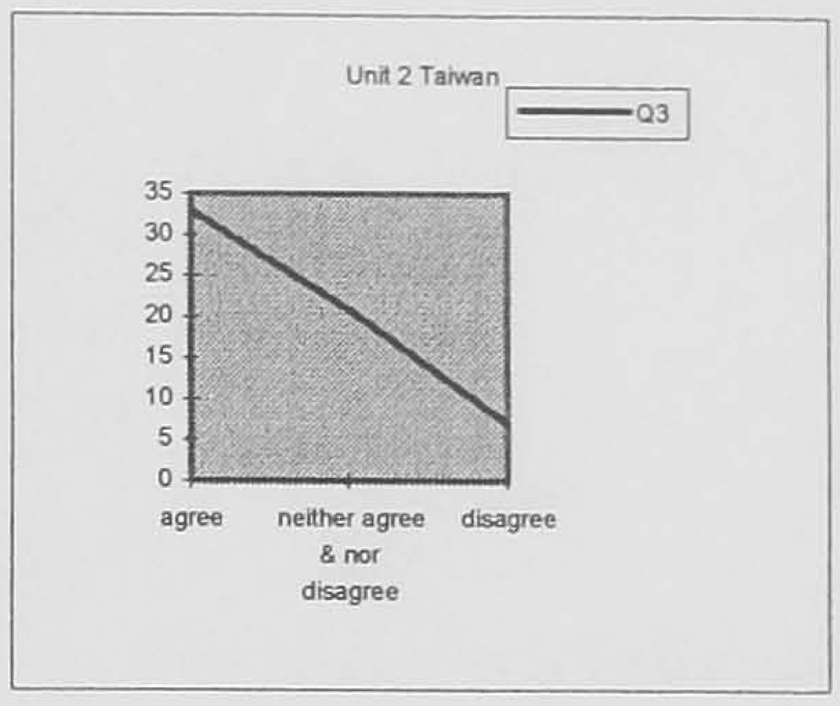
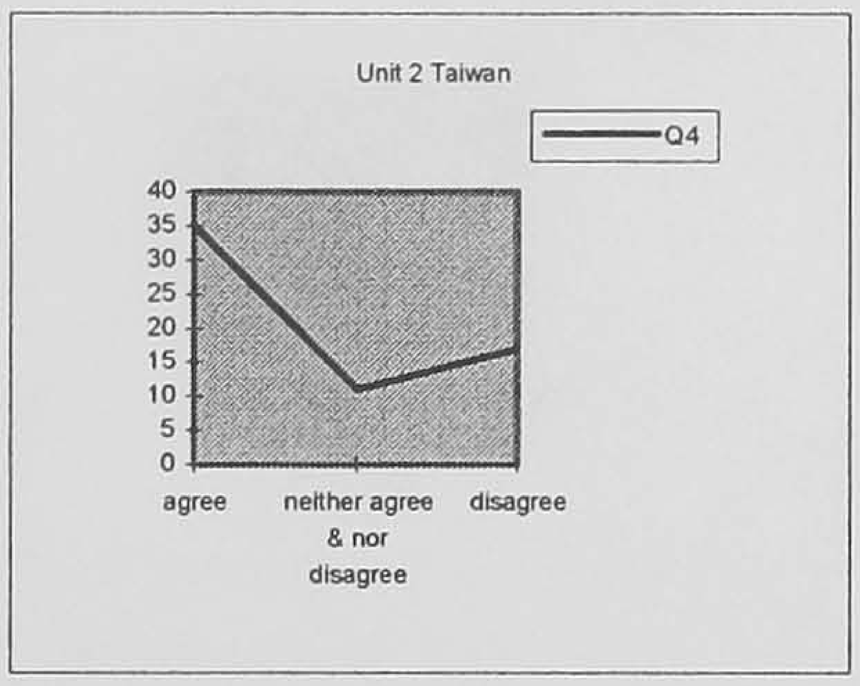
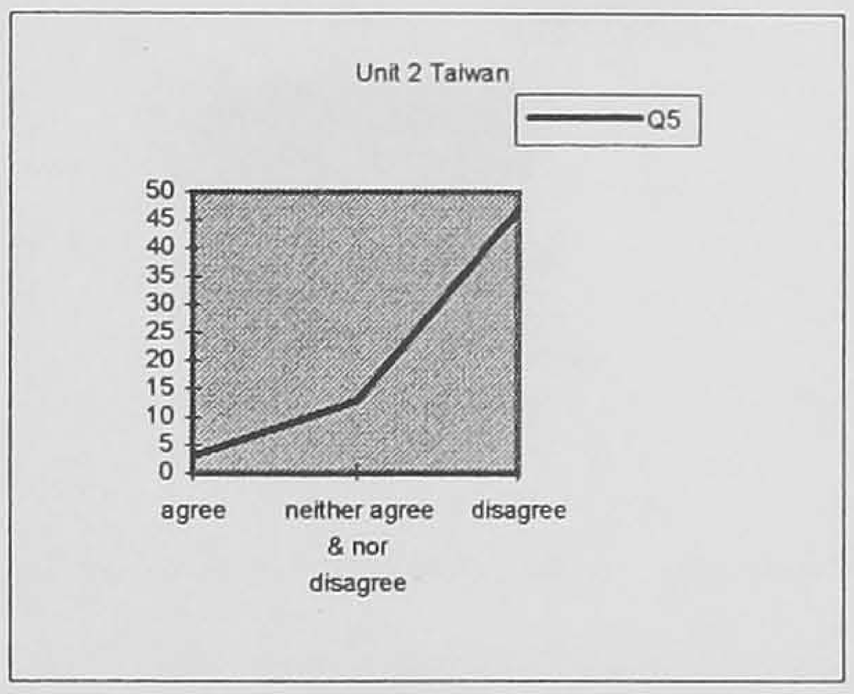
Unit 2 Taiwan

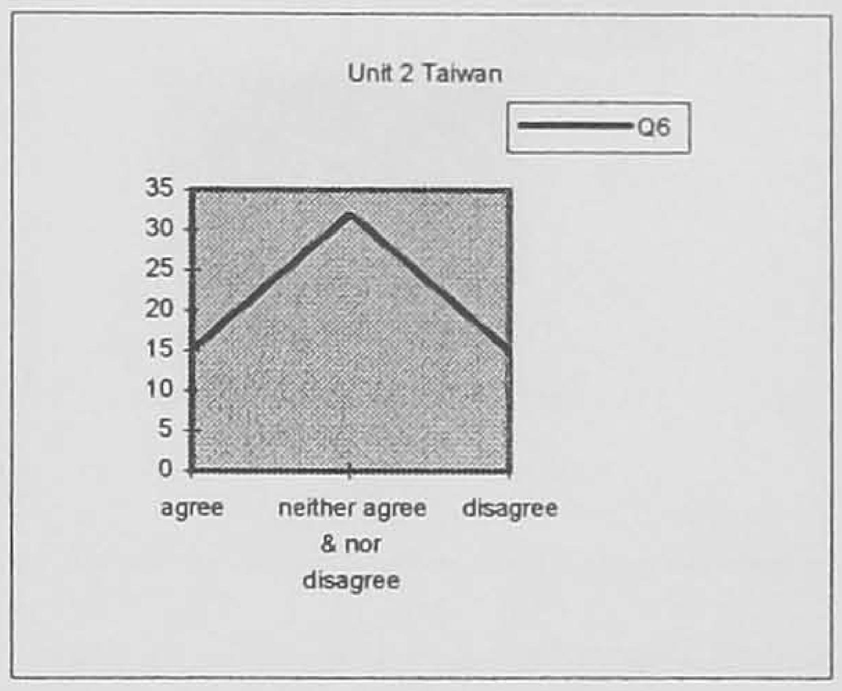


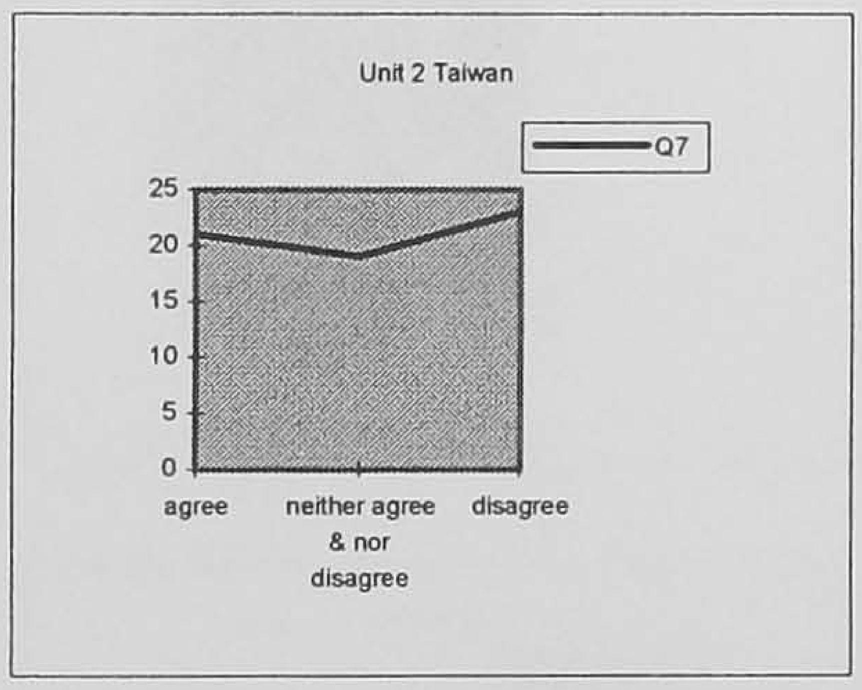


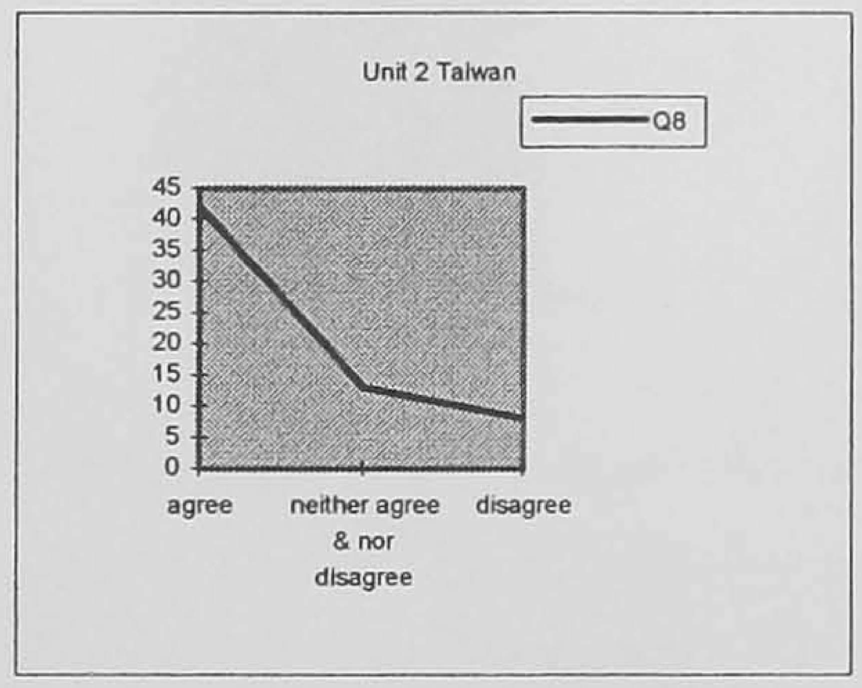


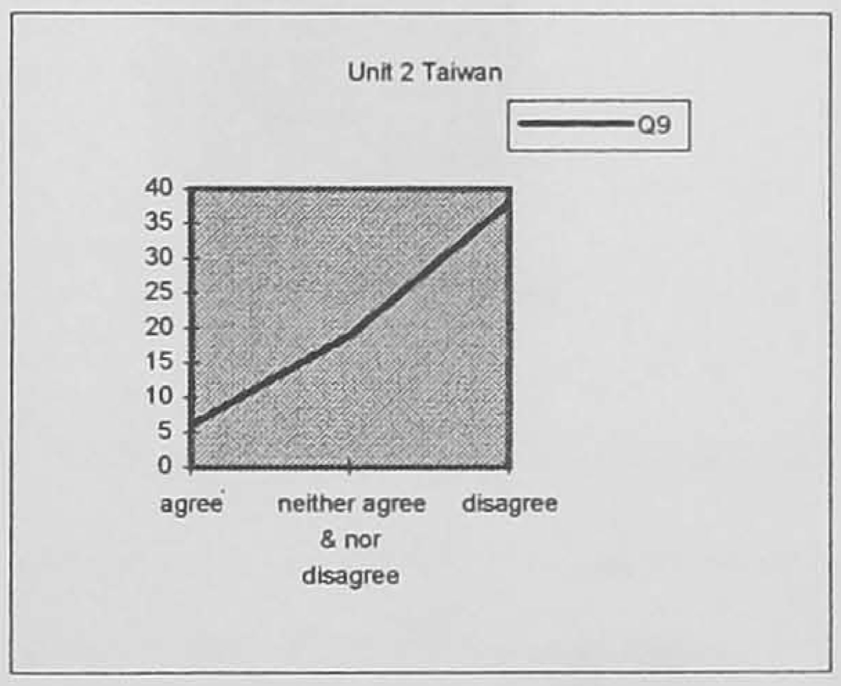


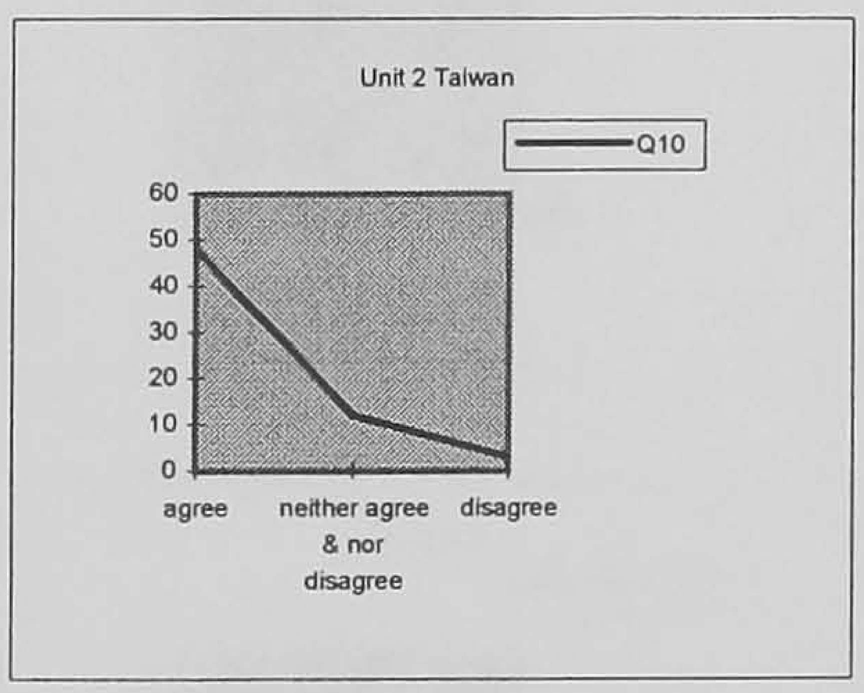


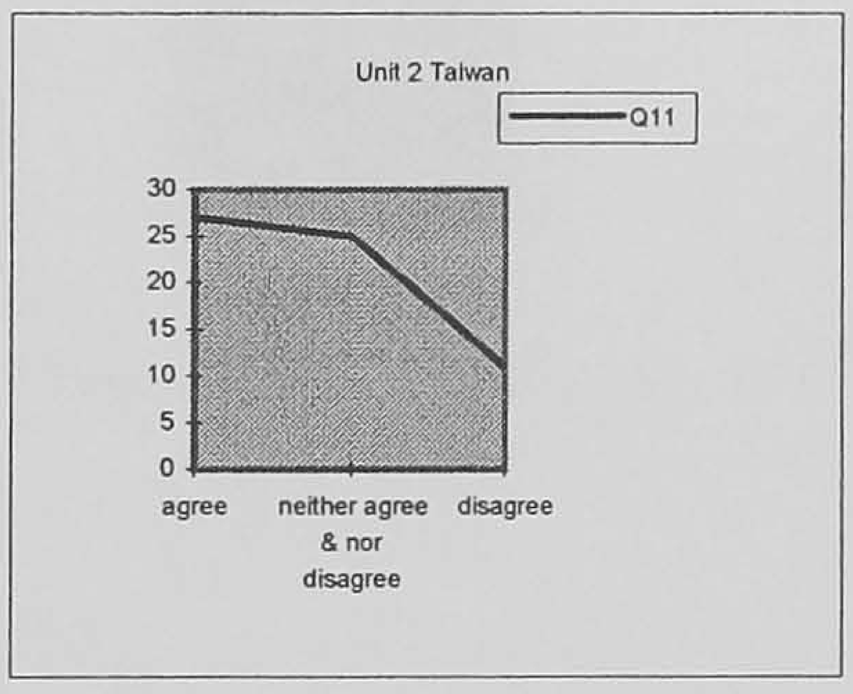


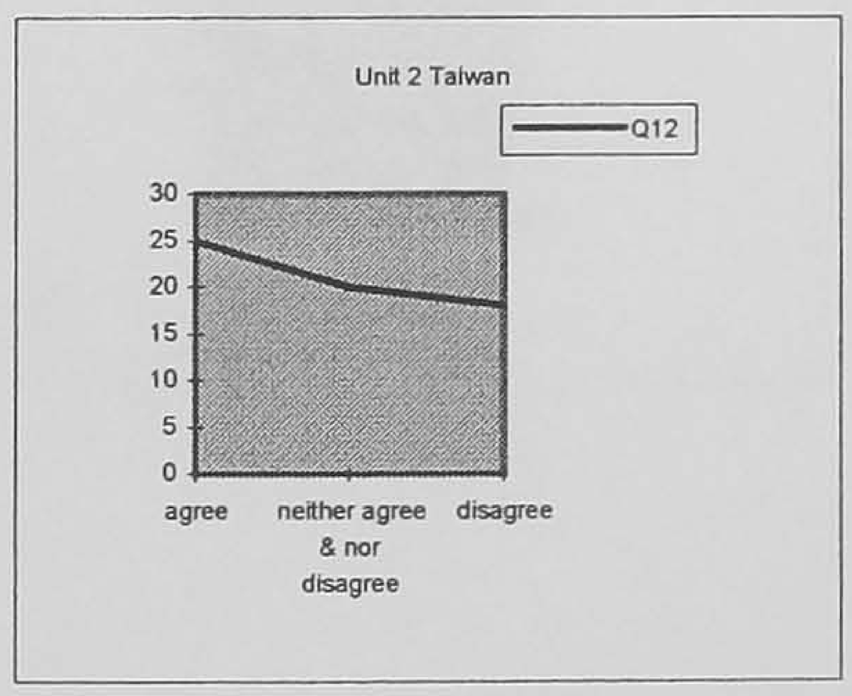


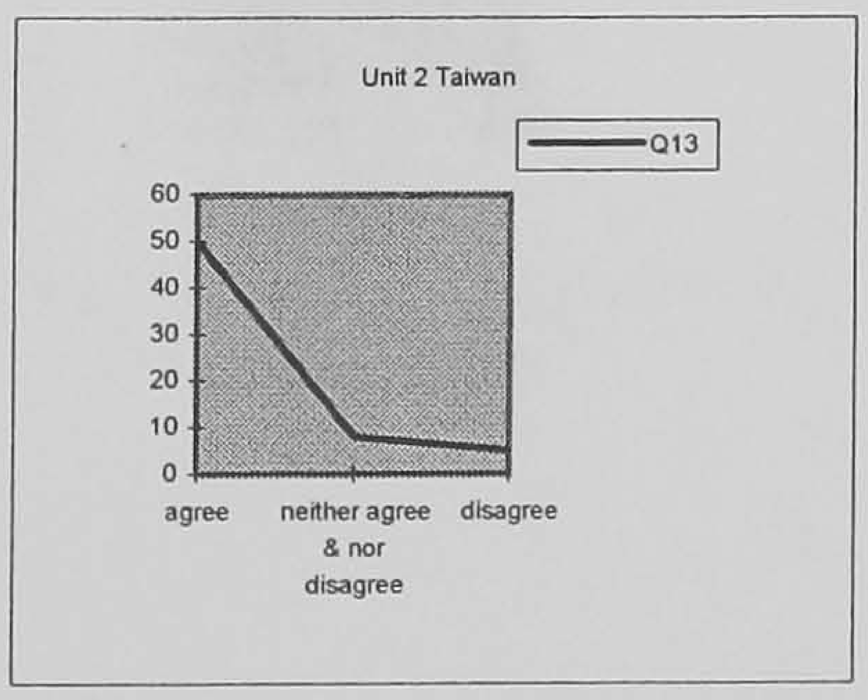




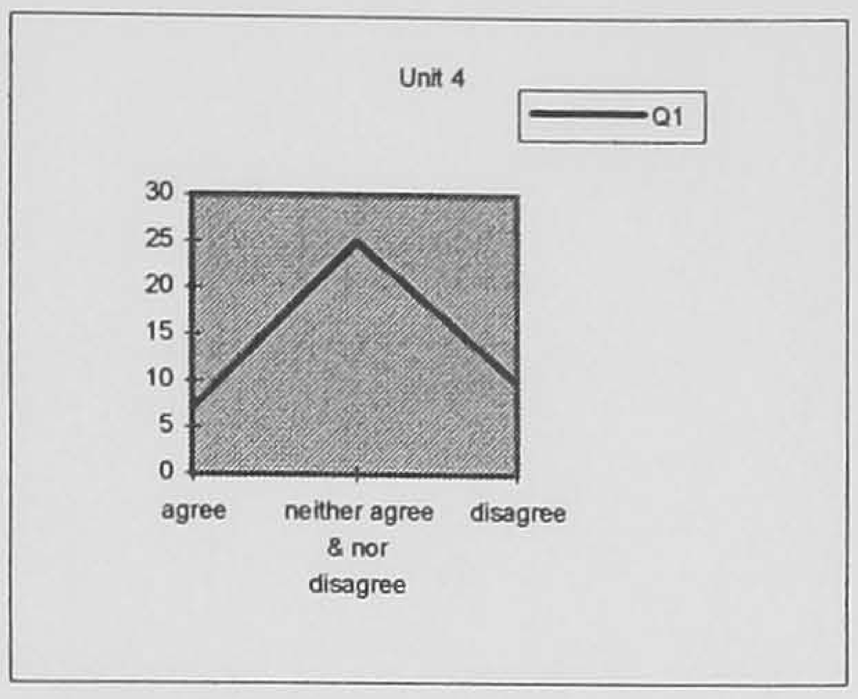








Unit 4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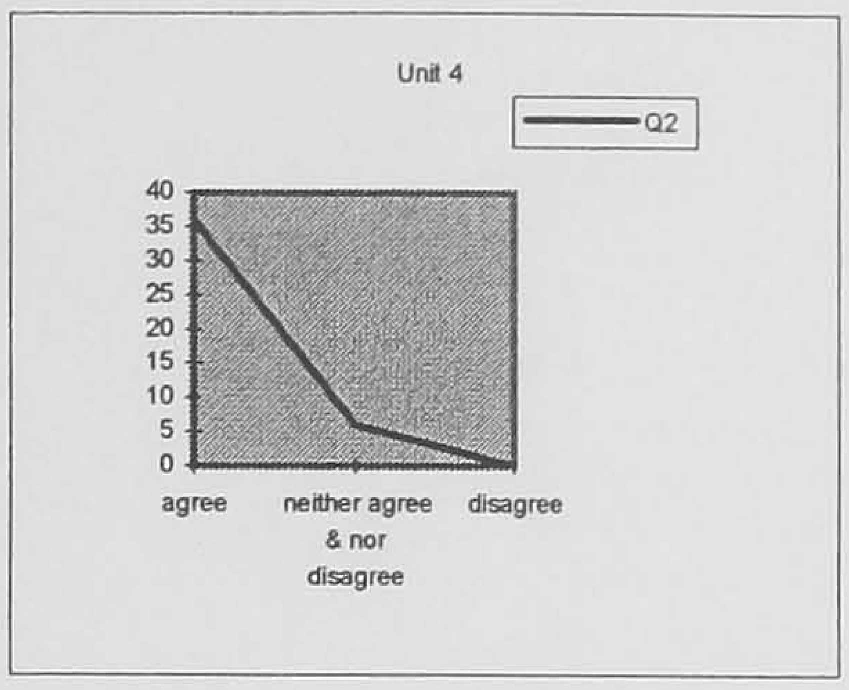
disagree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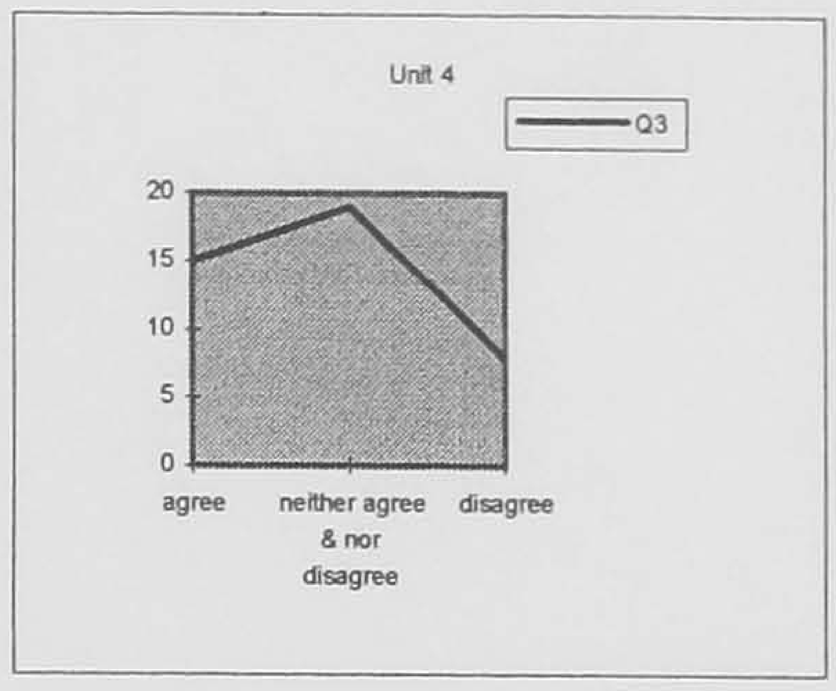
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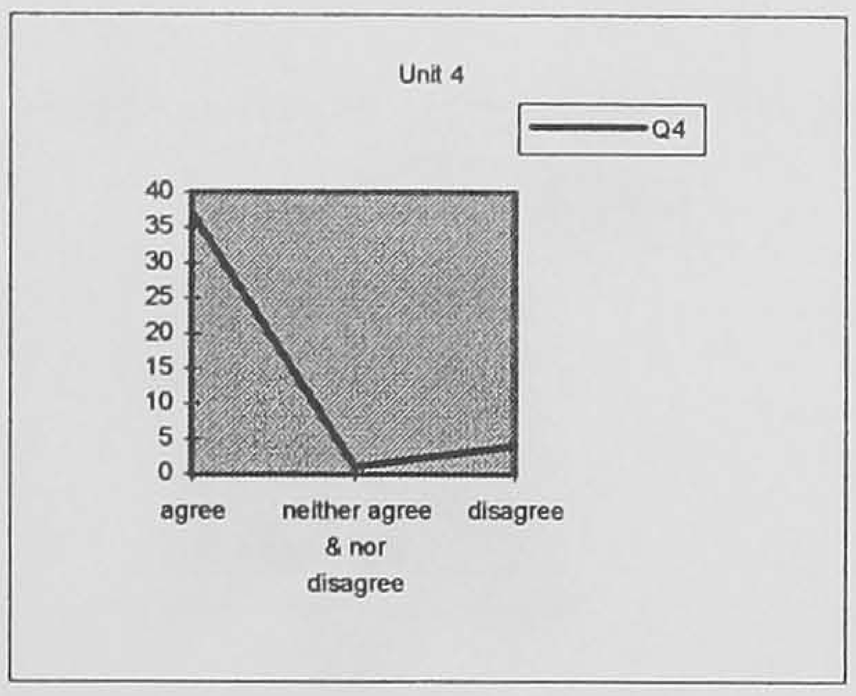
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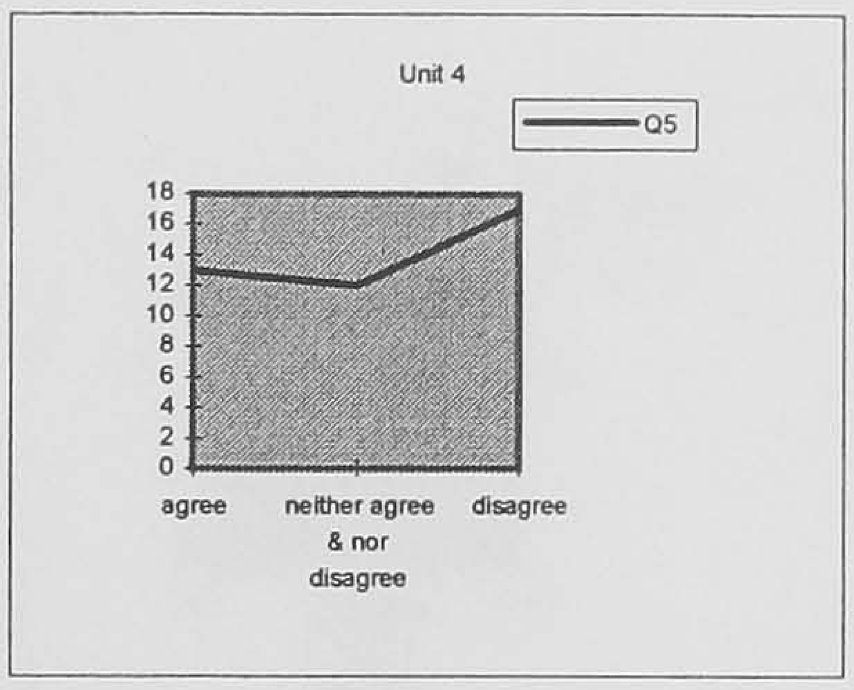
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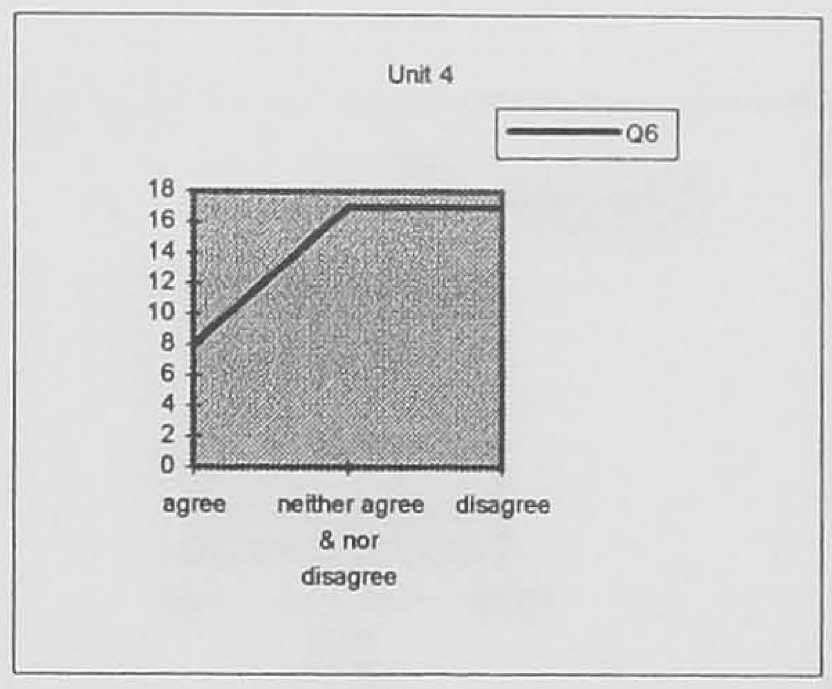
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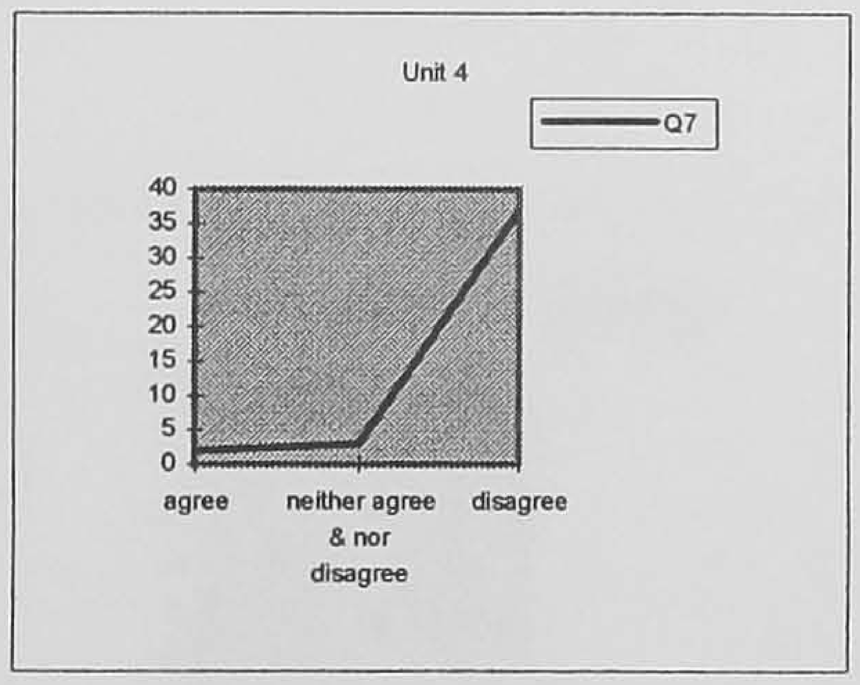
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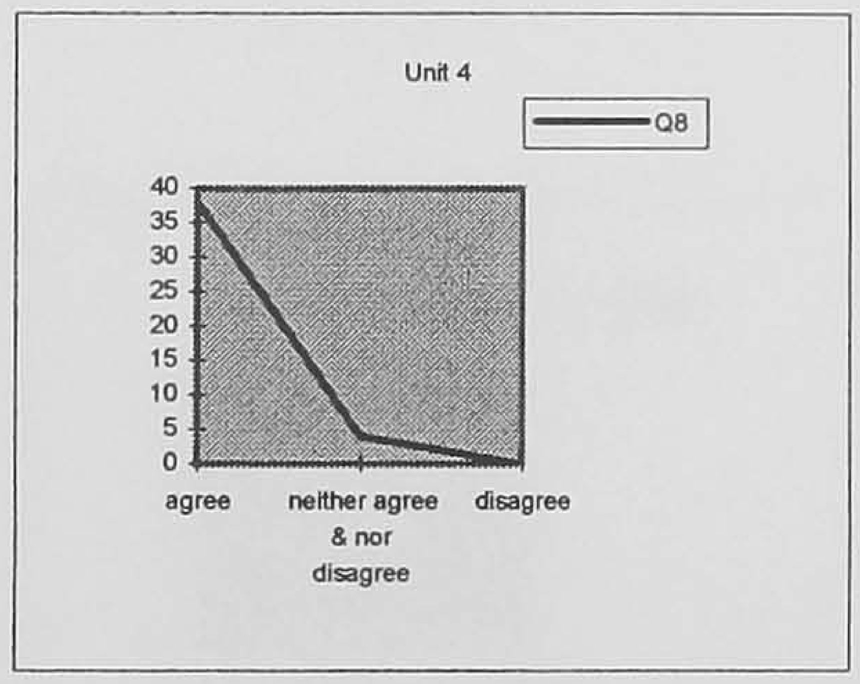
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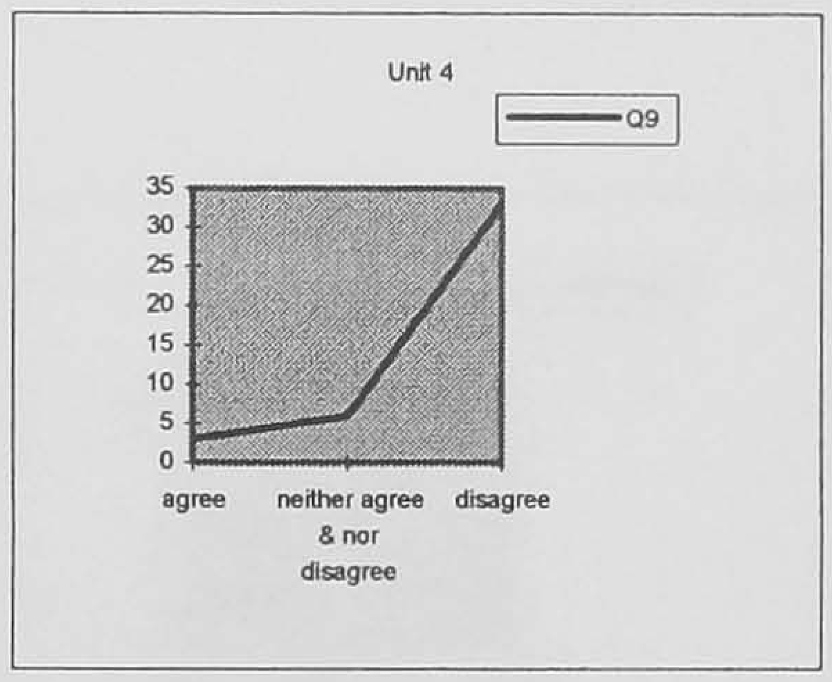
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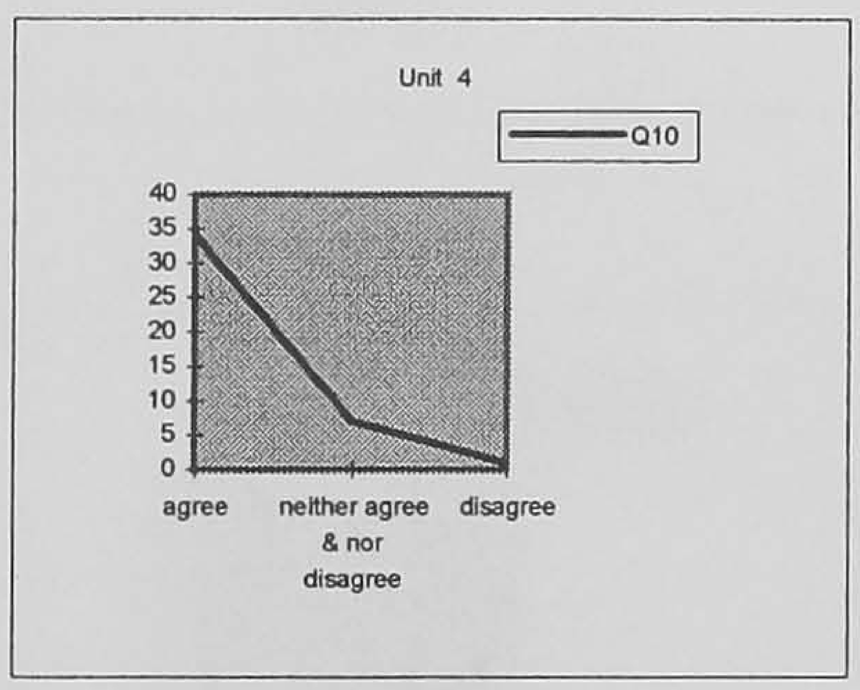
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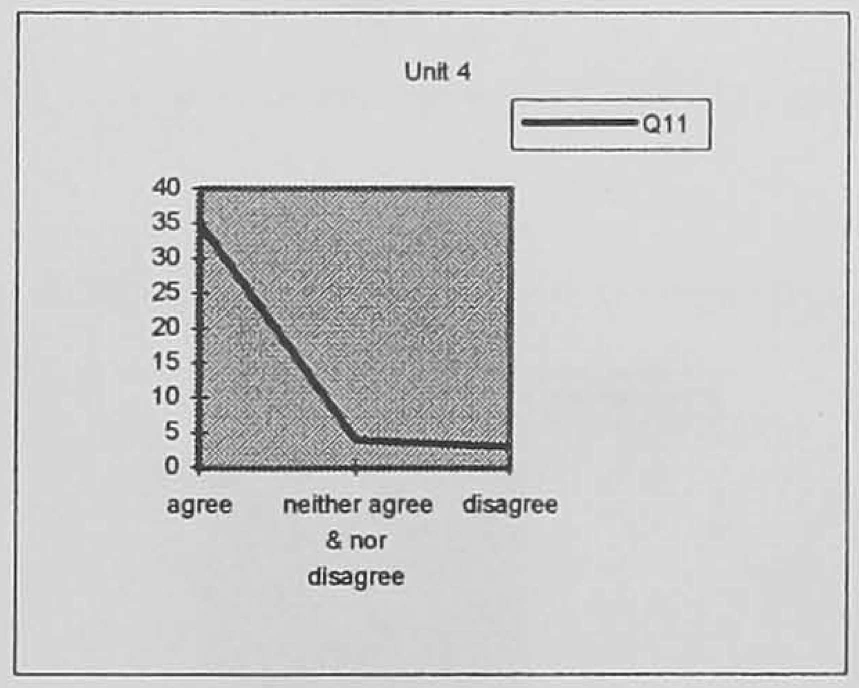
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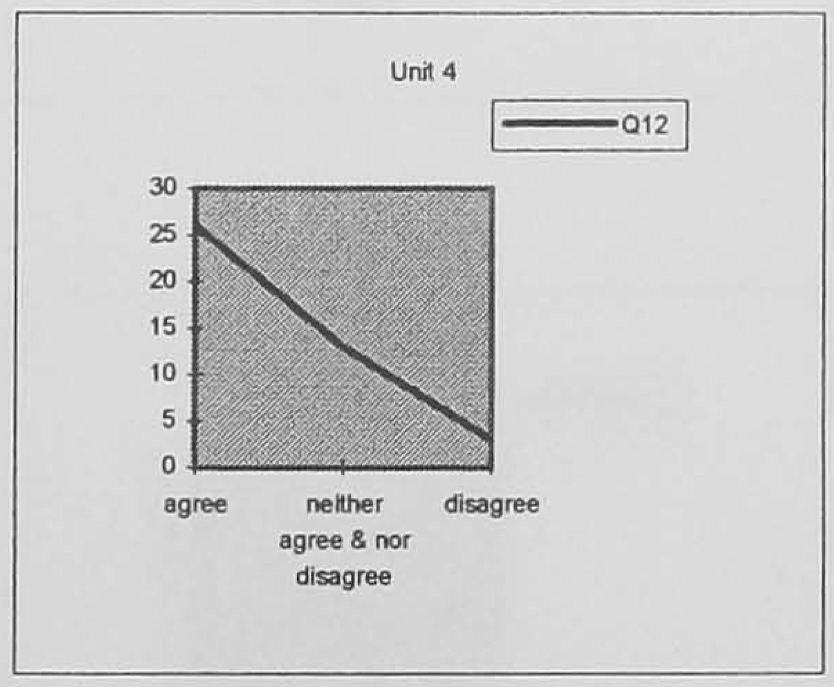
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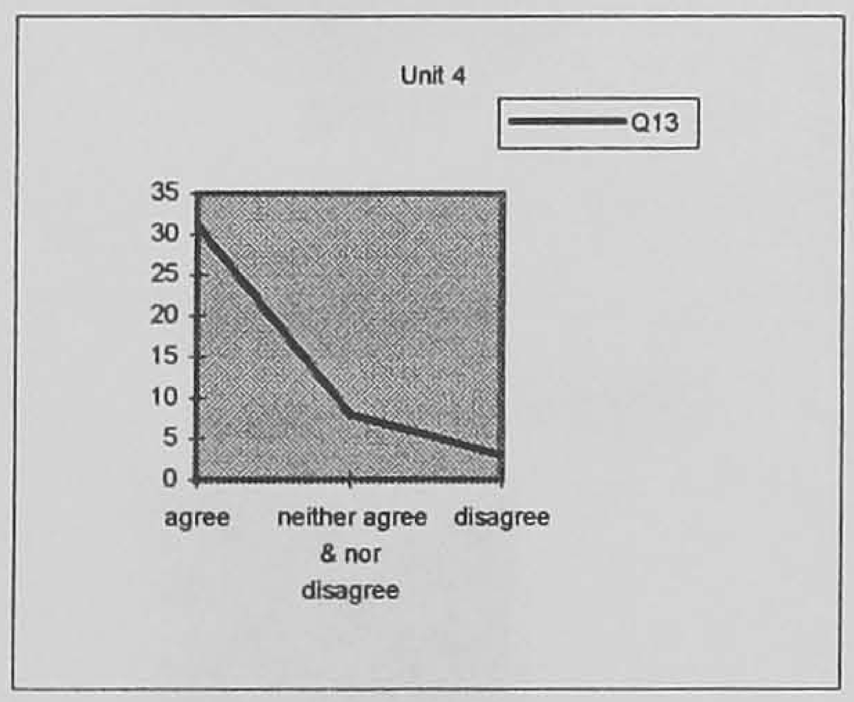
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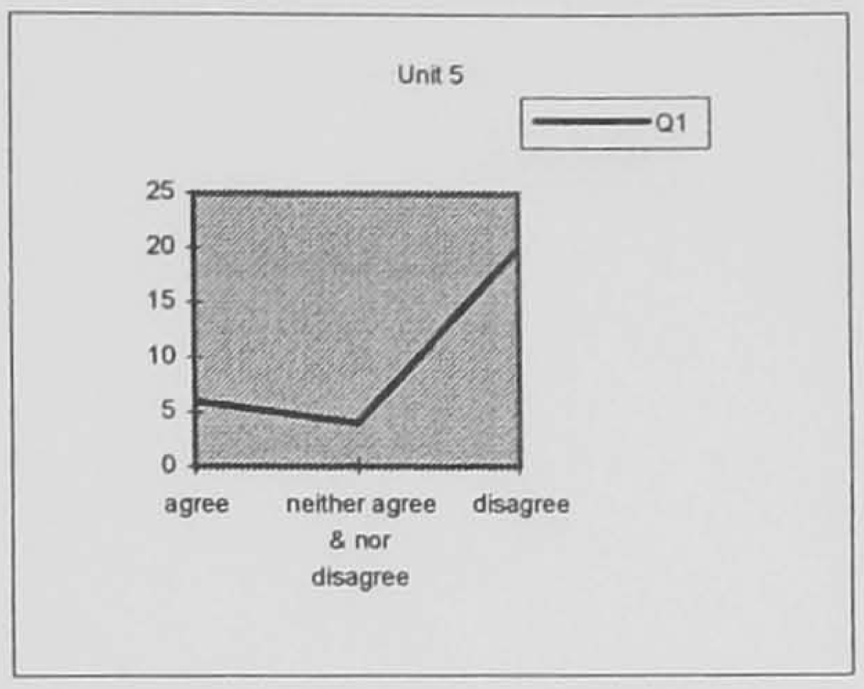
Unit 5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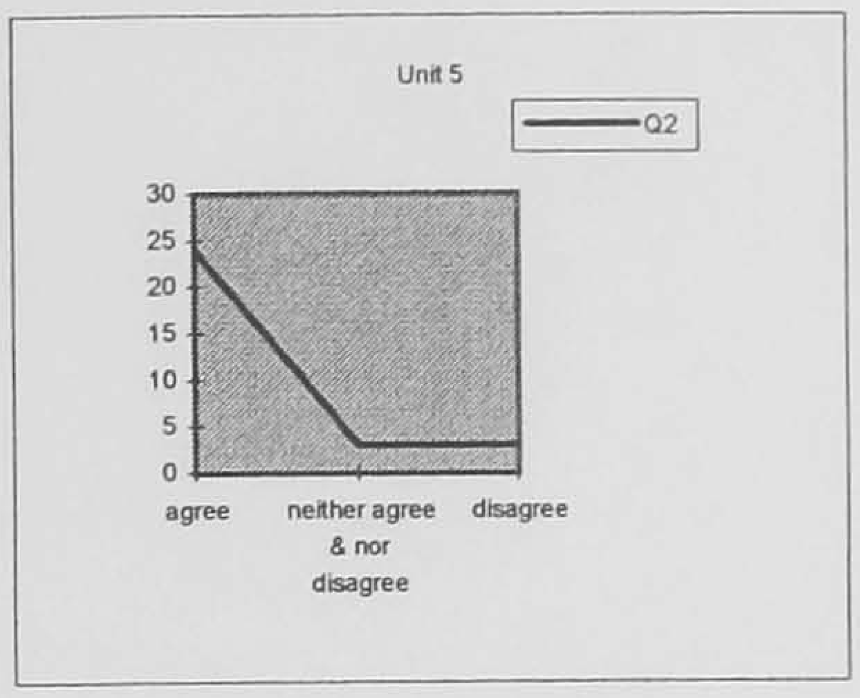
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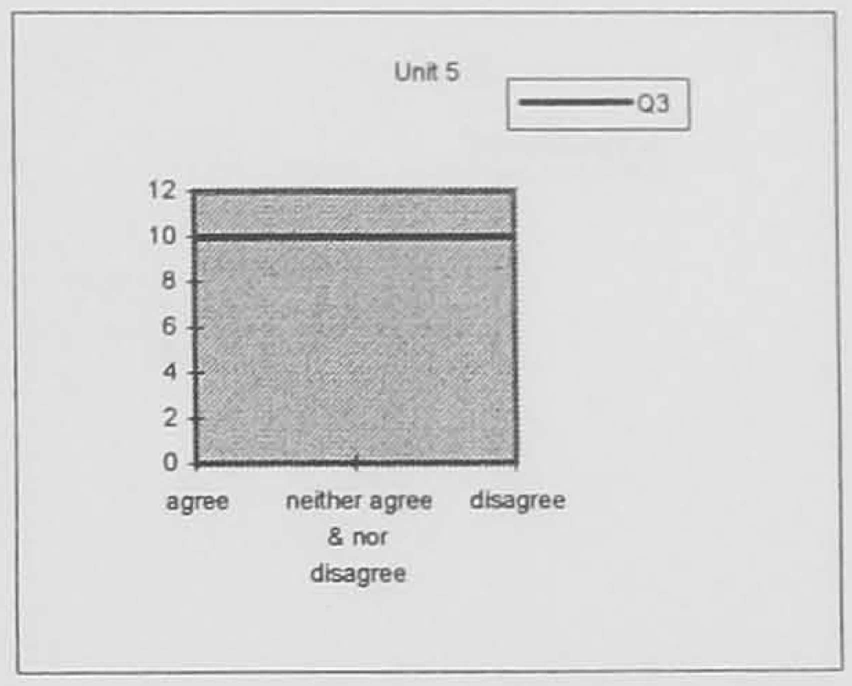
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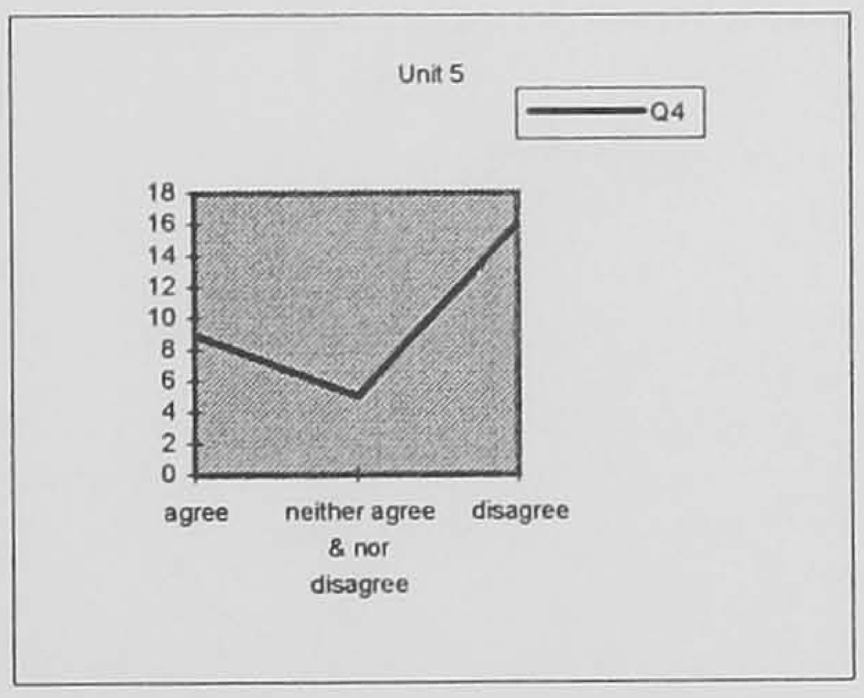
disagree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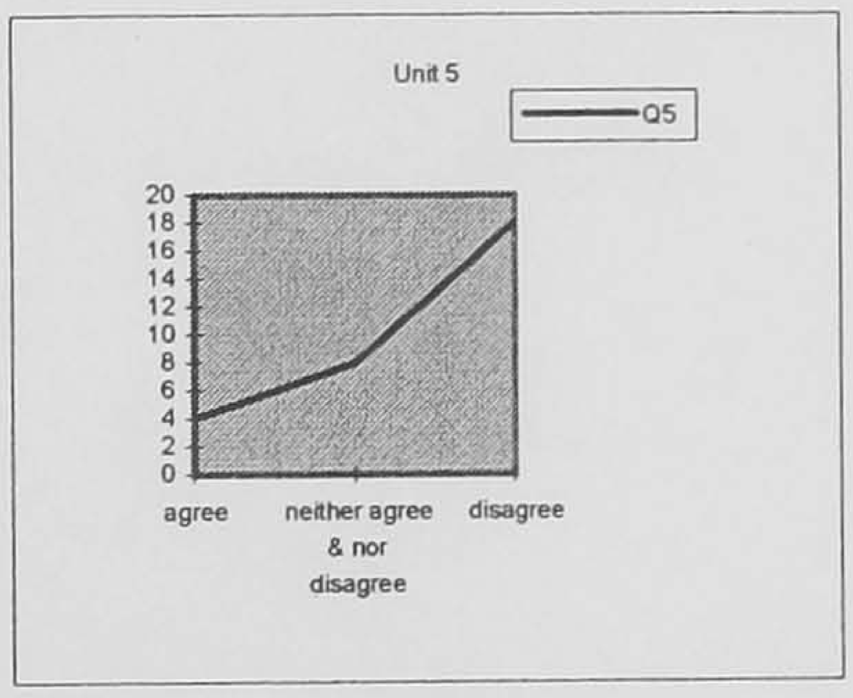
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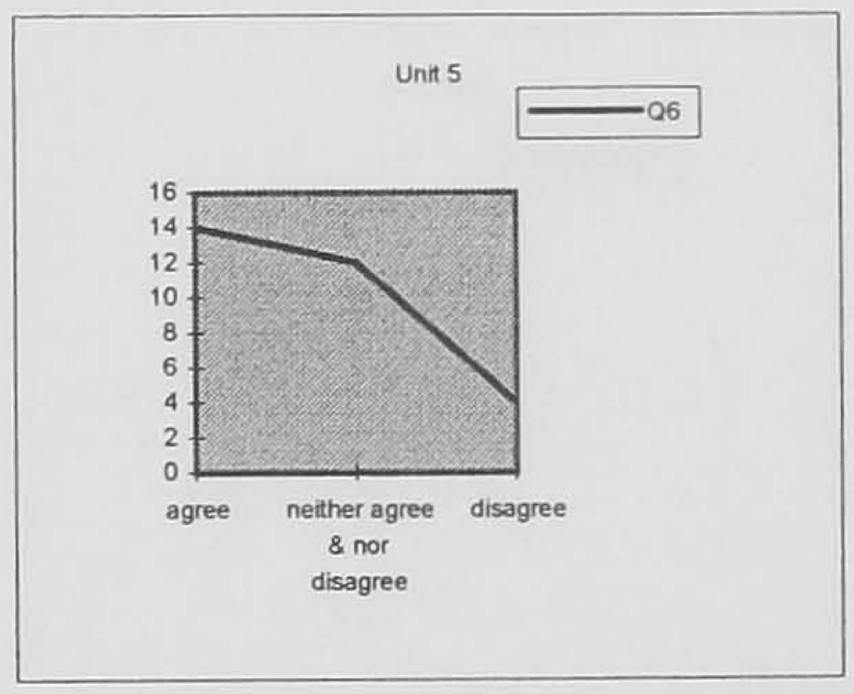
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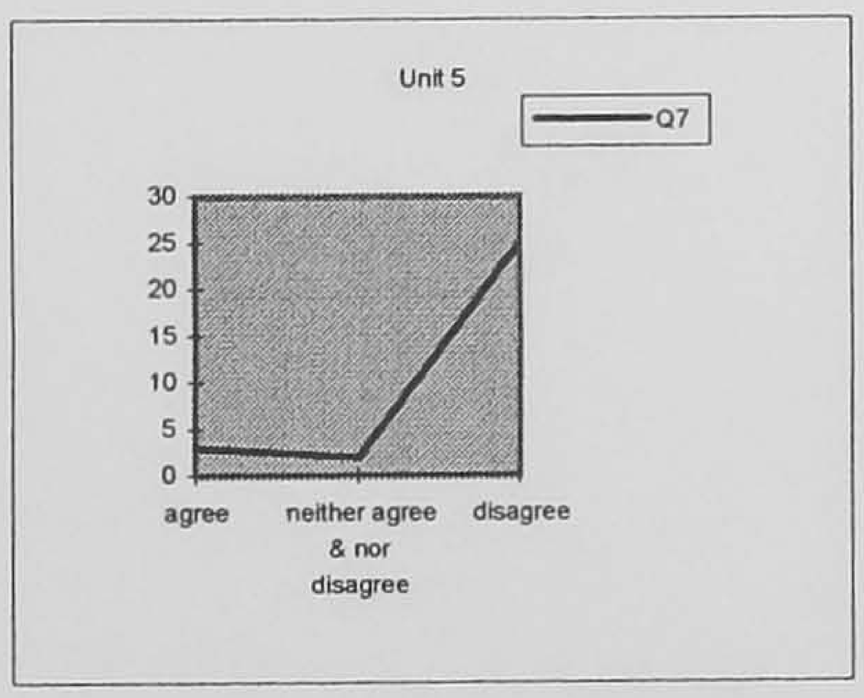
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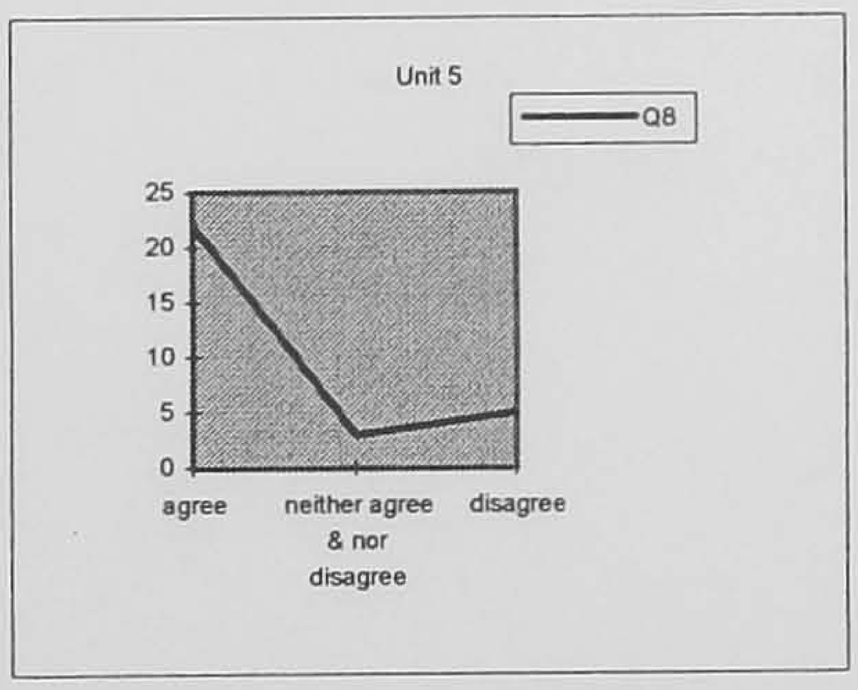
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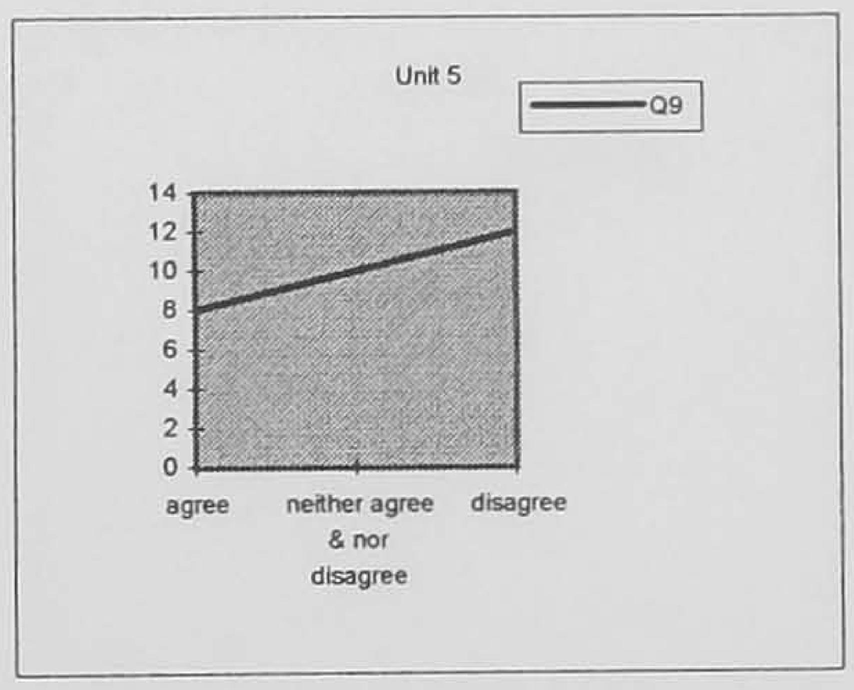
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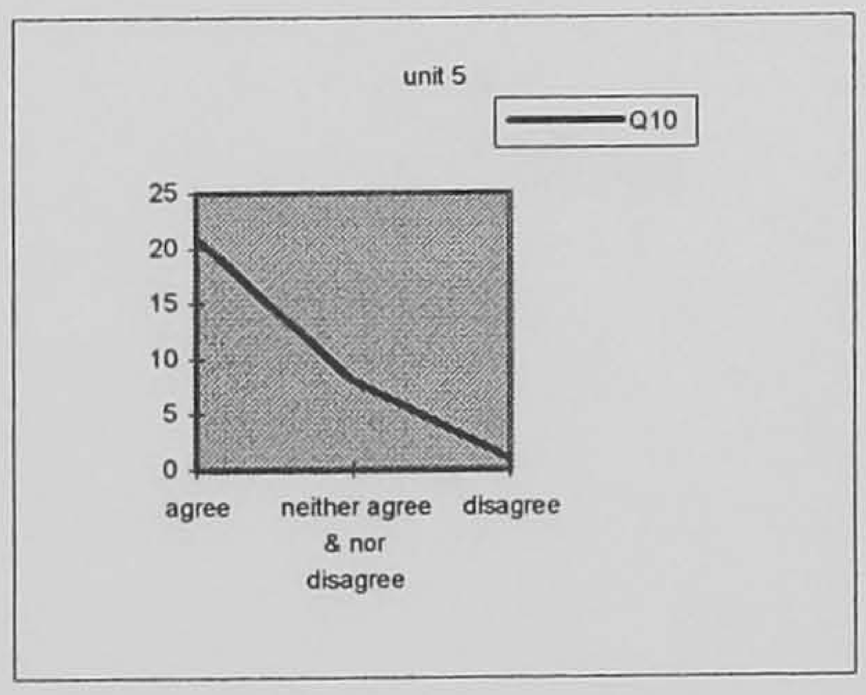
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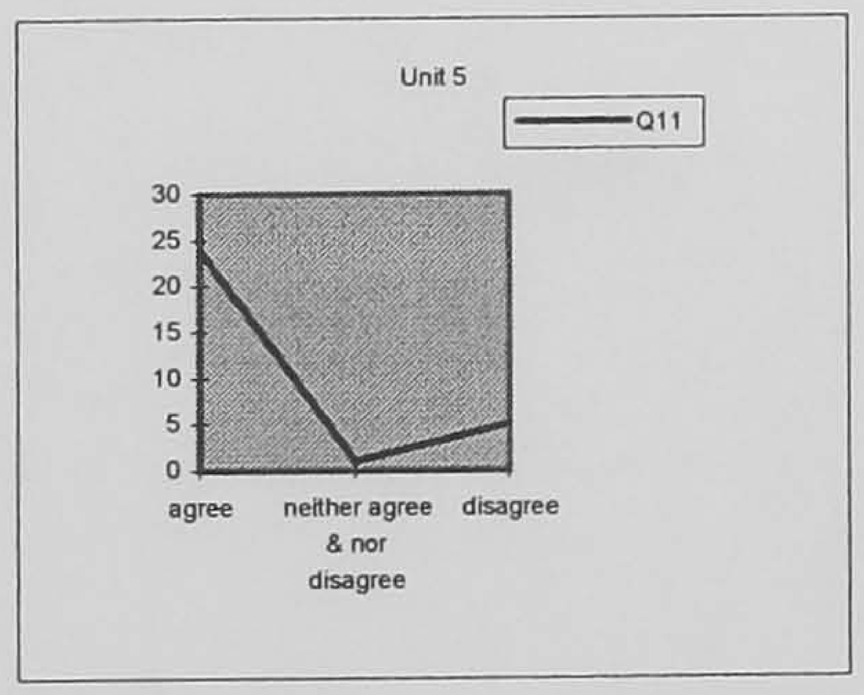
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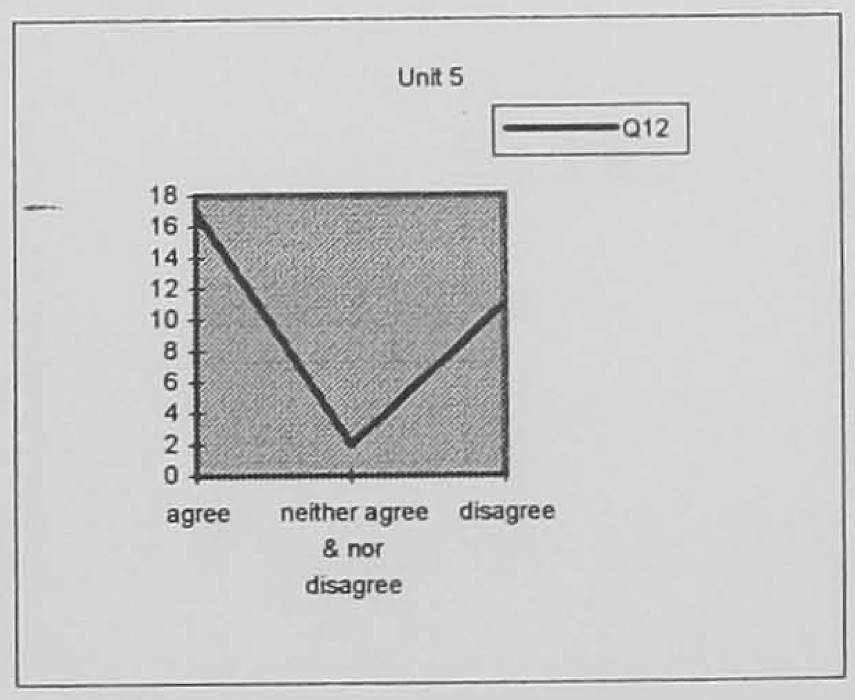
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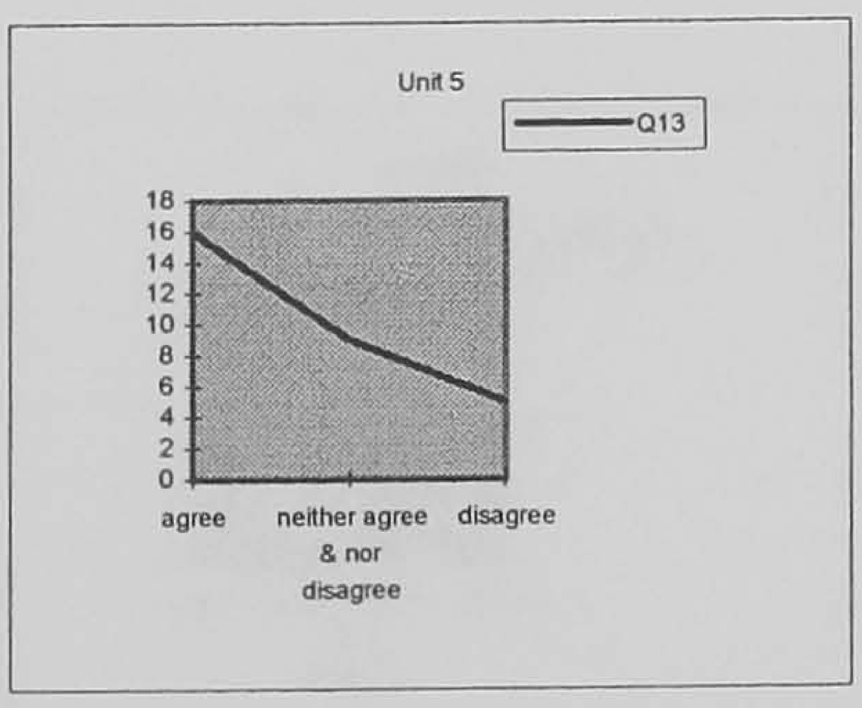
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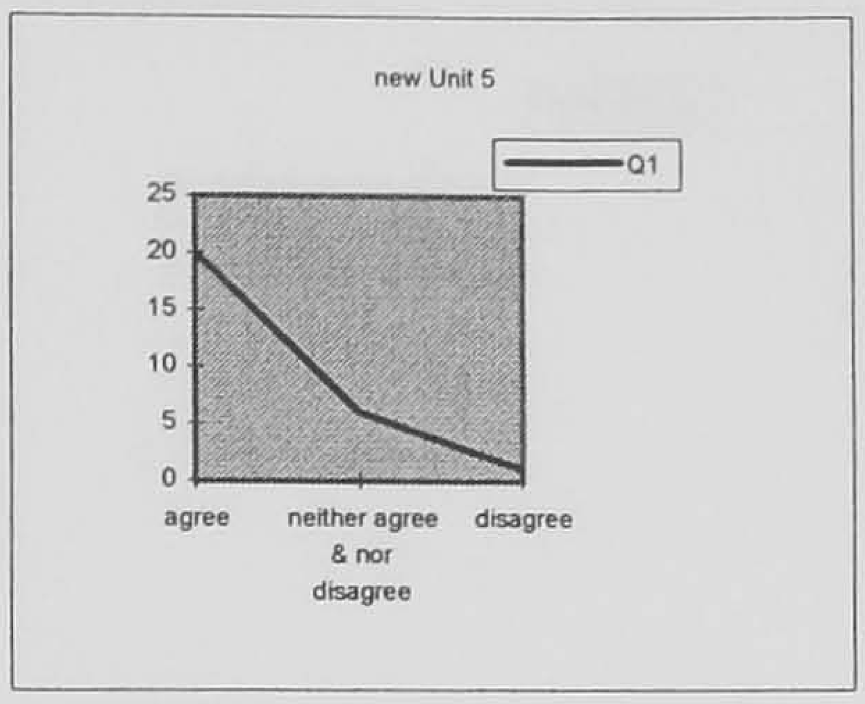
New Unit 5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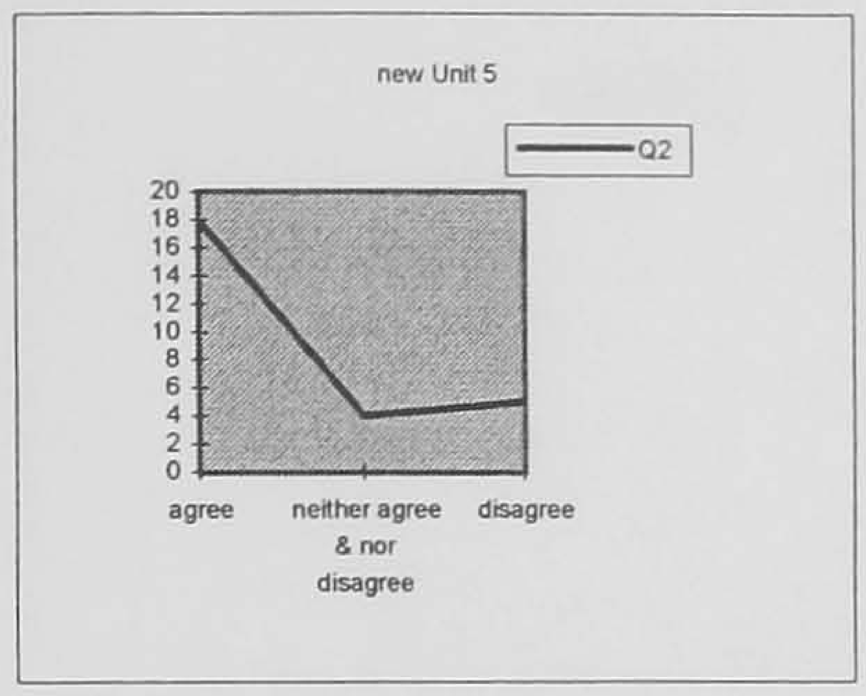
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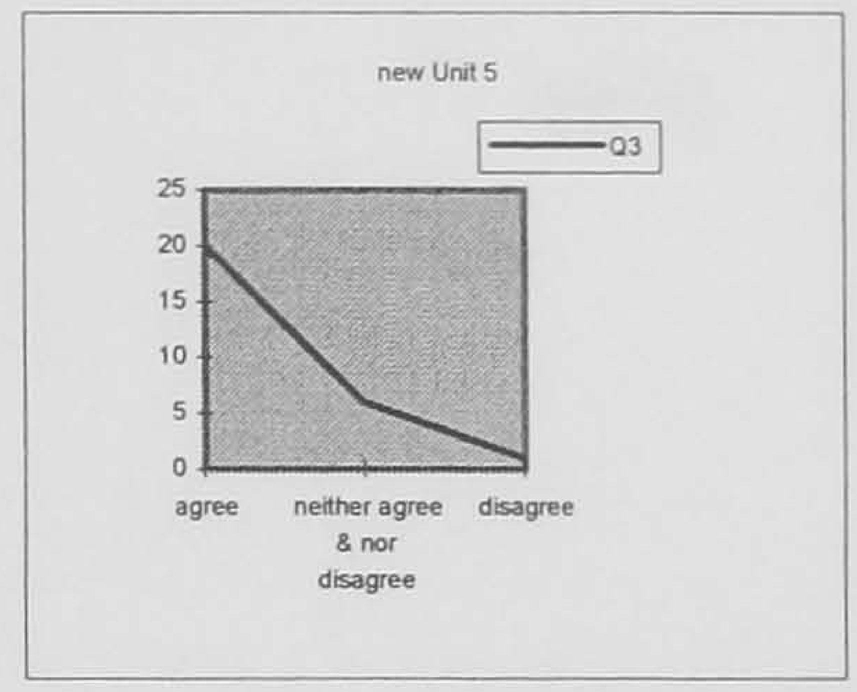
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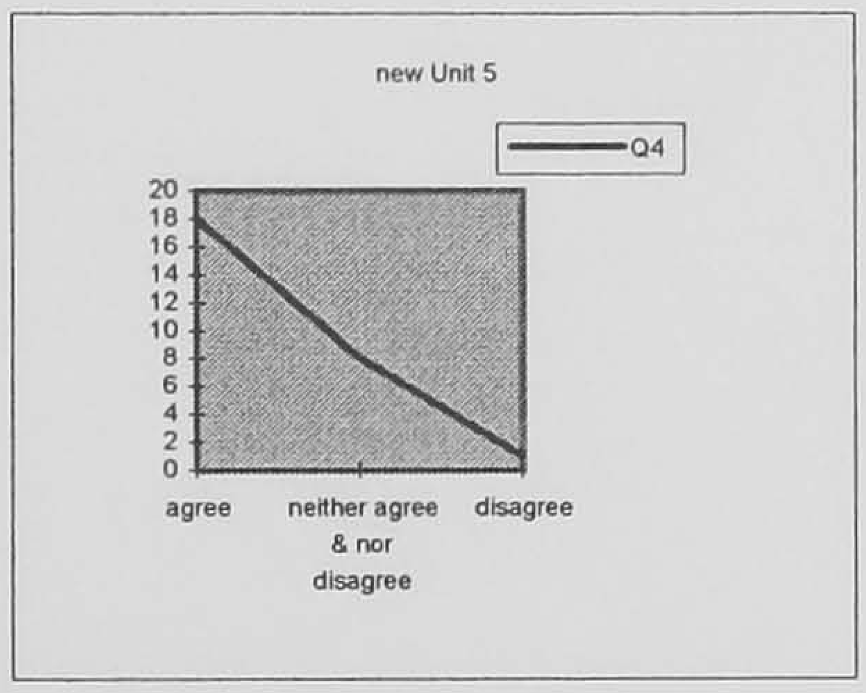
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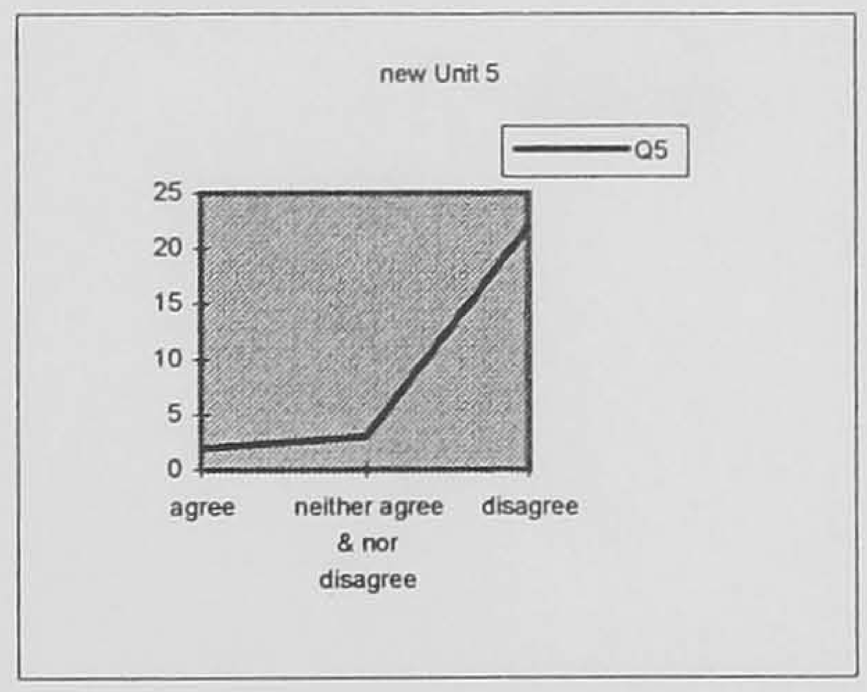
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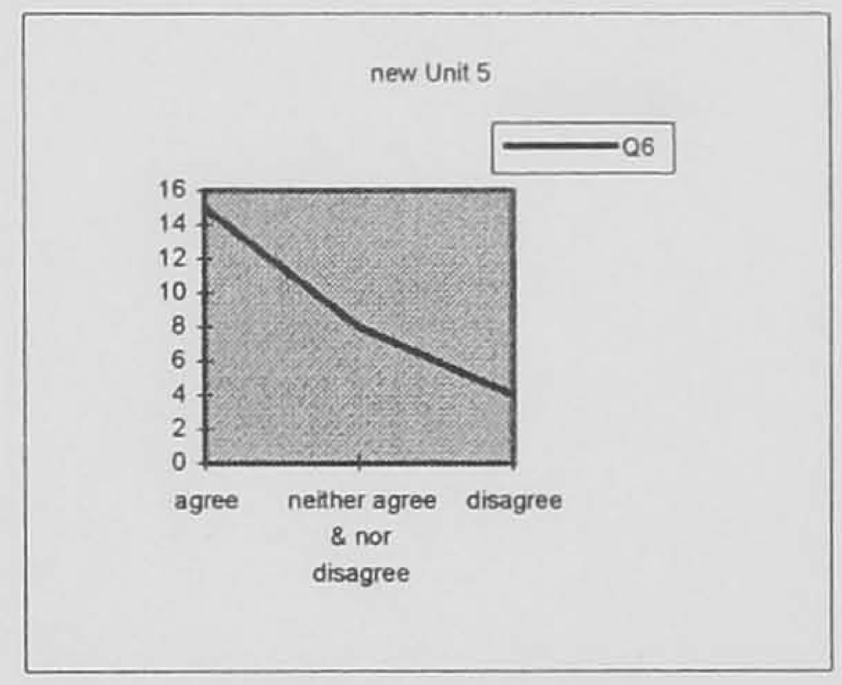
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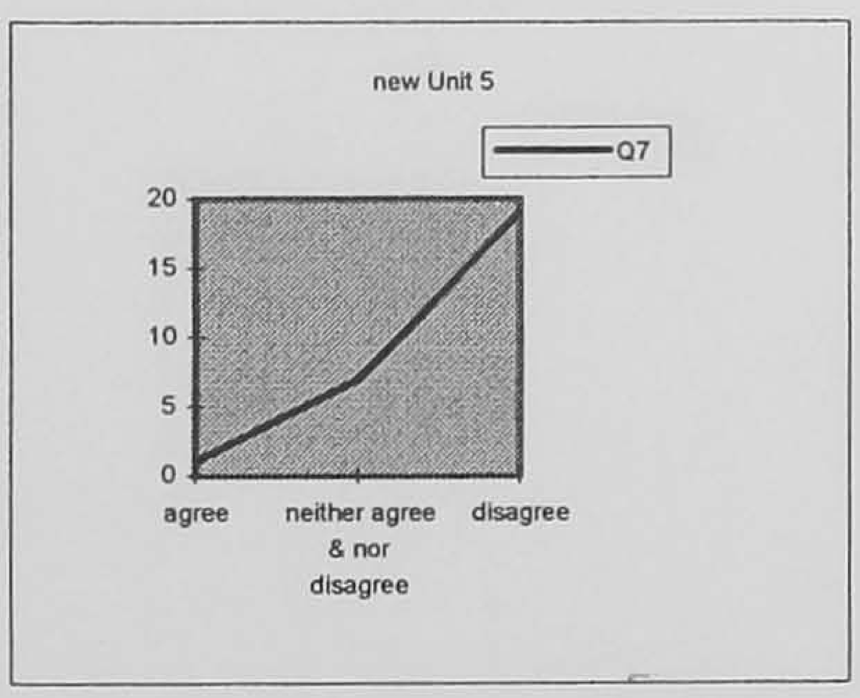
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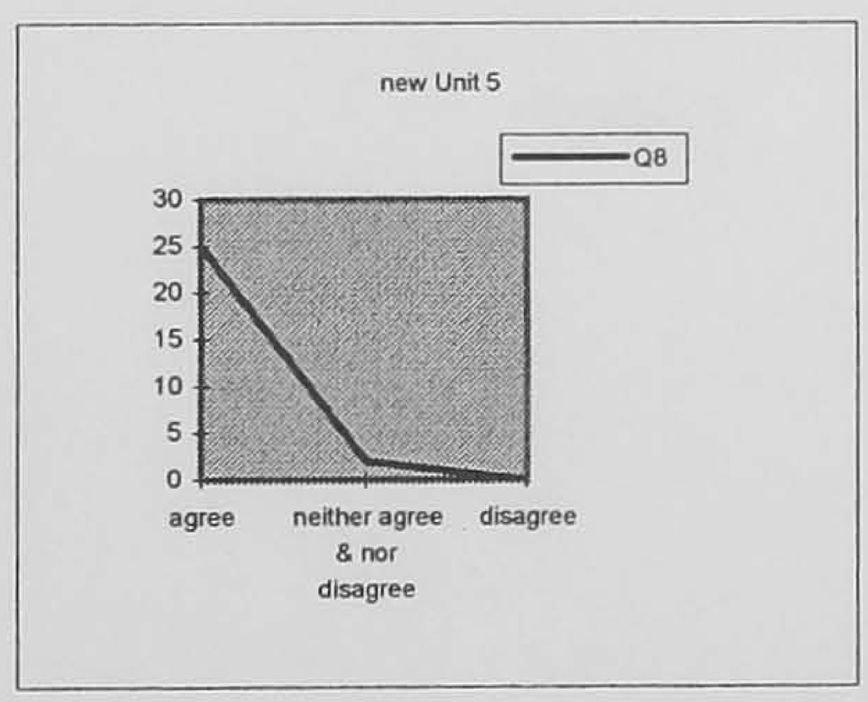
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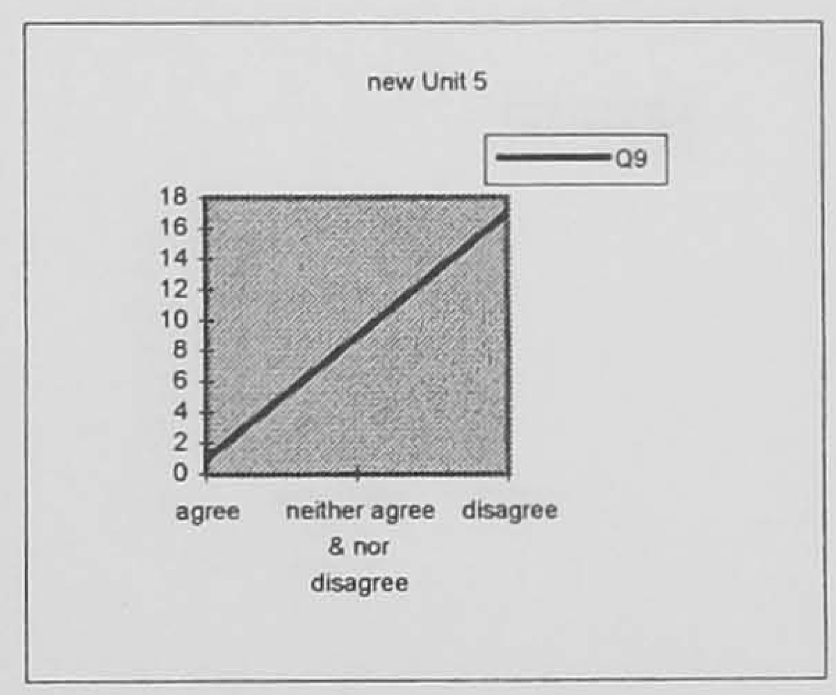
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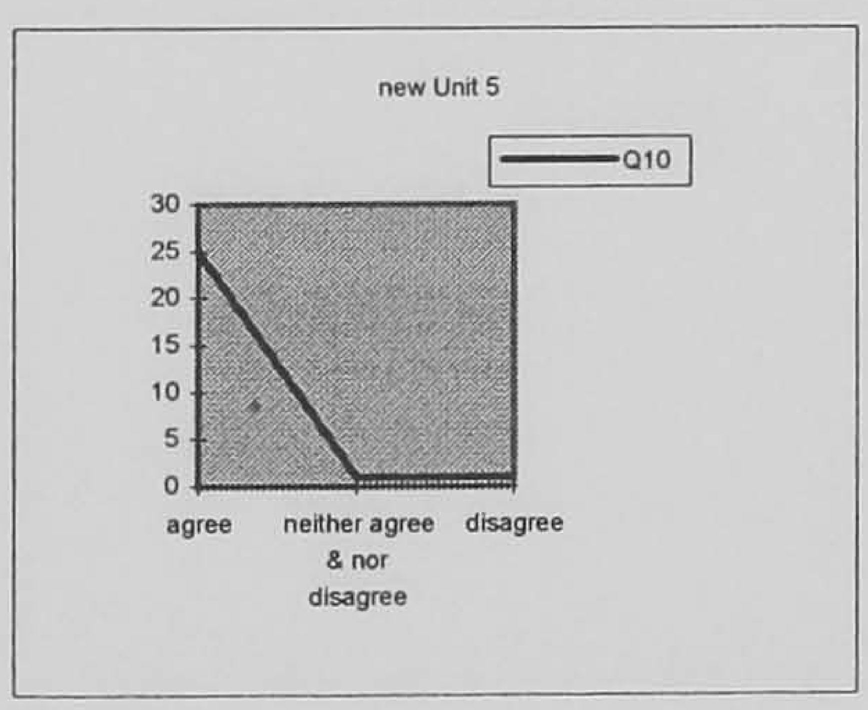
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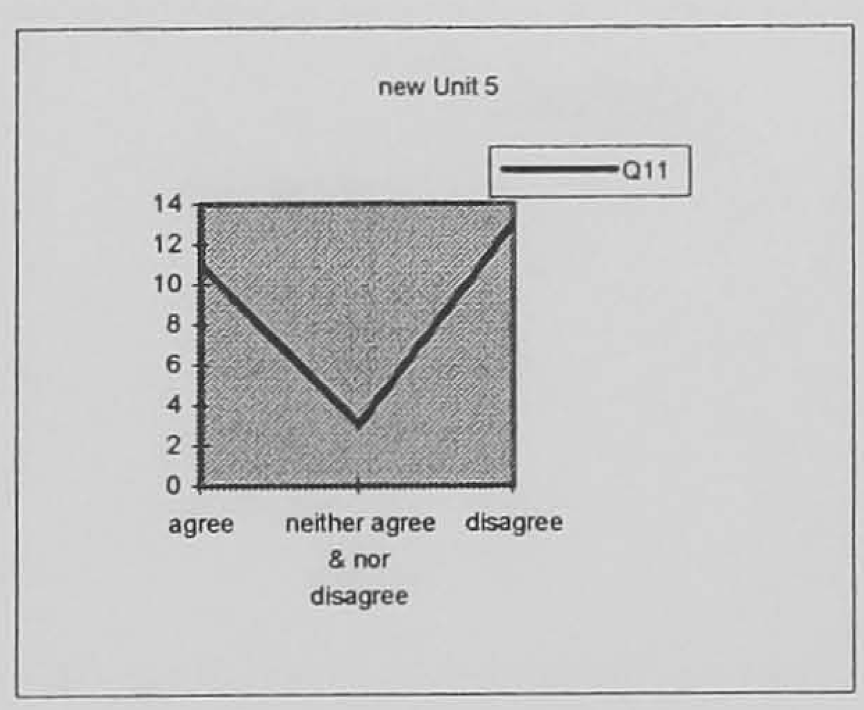
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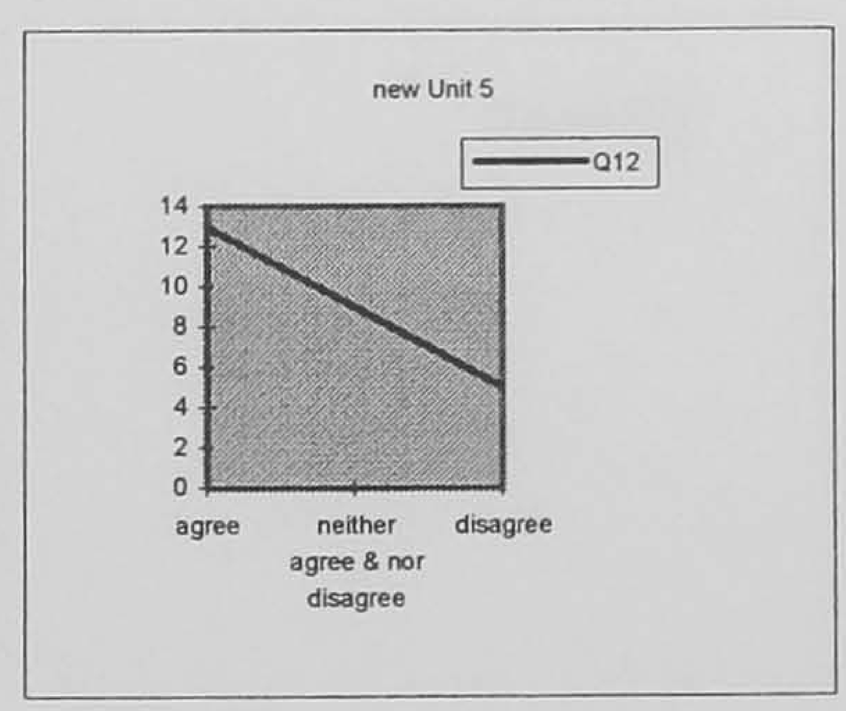
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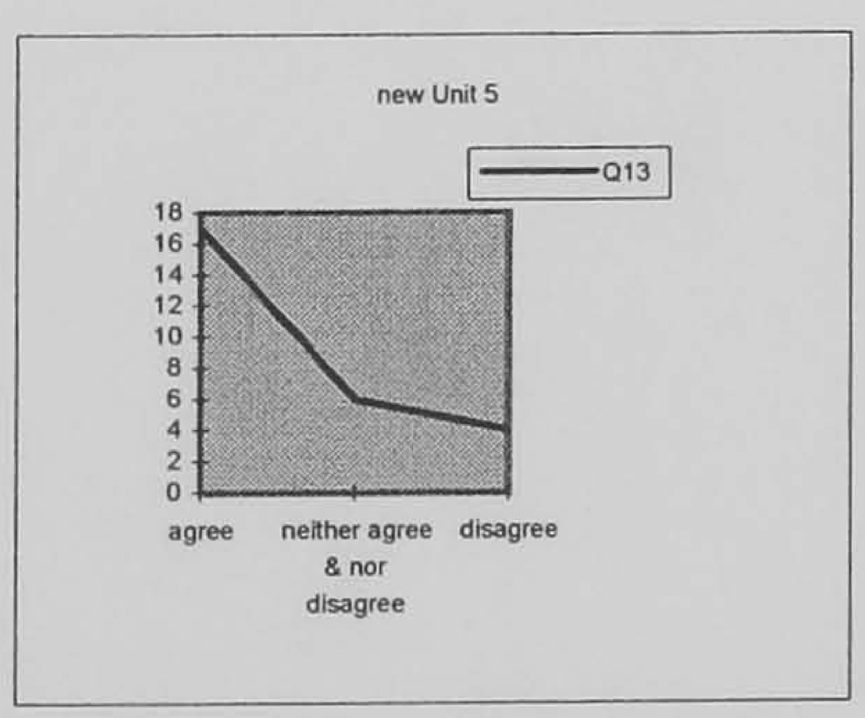
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agree
neither agree & nor disagree
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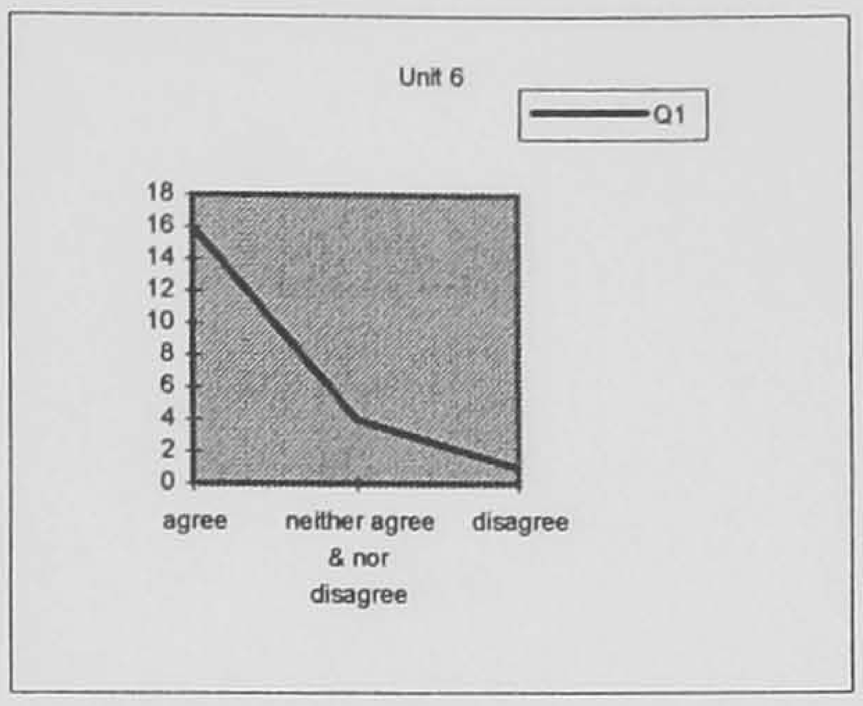
Unit 6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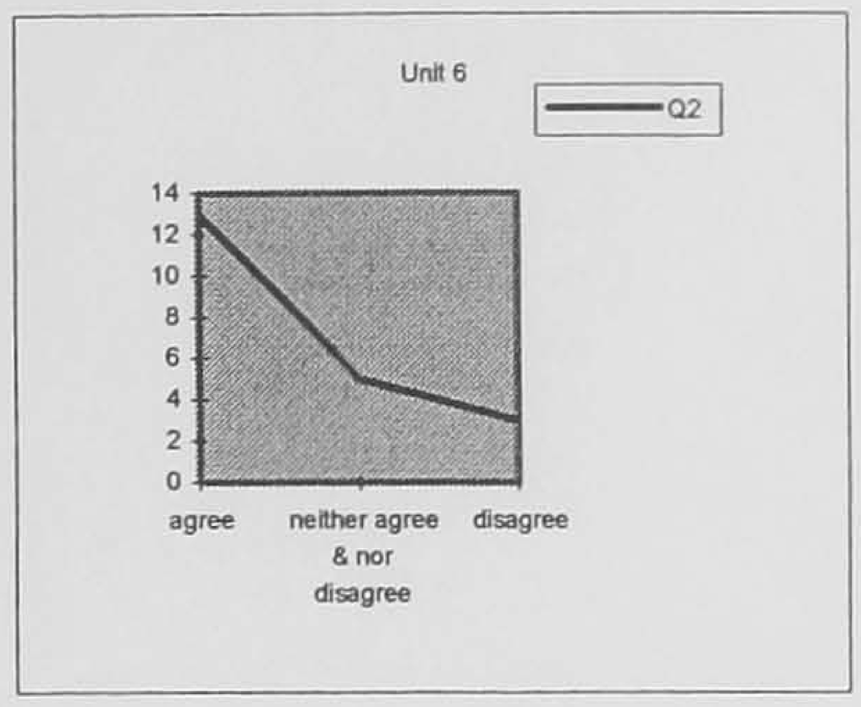
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Q2
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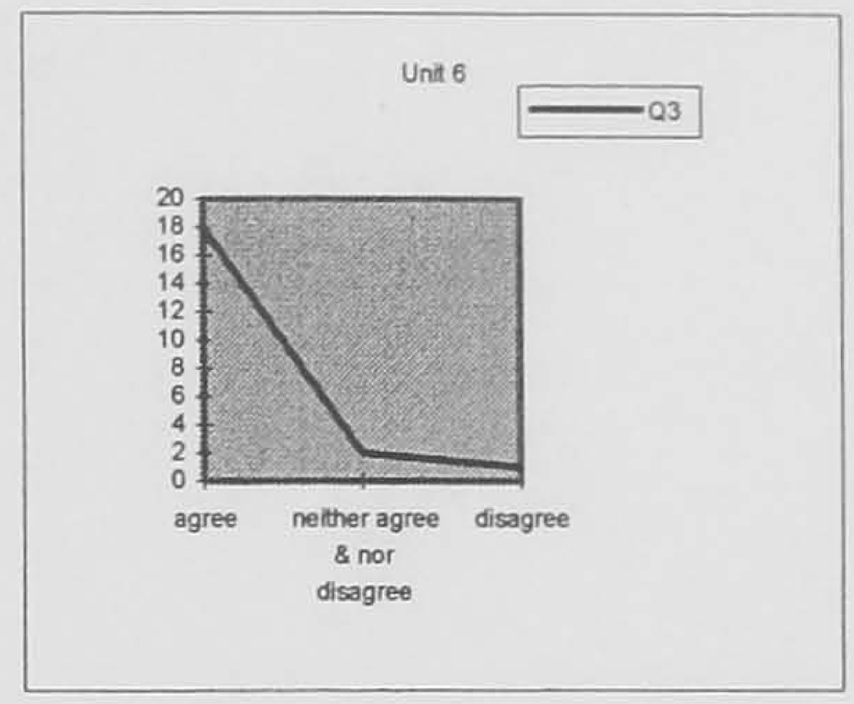
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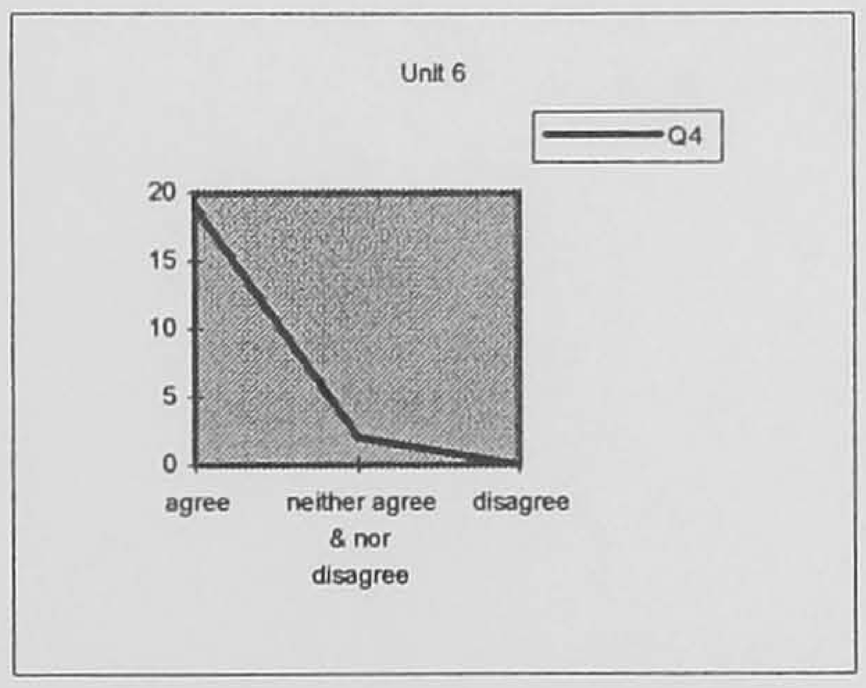
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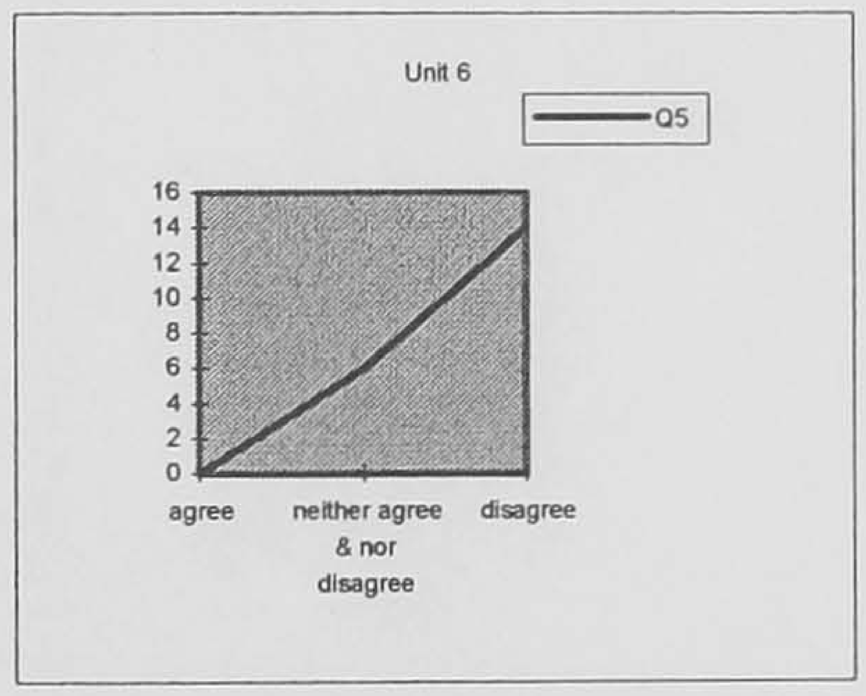
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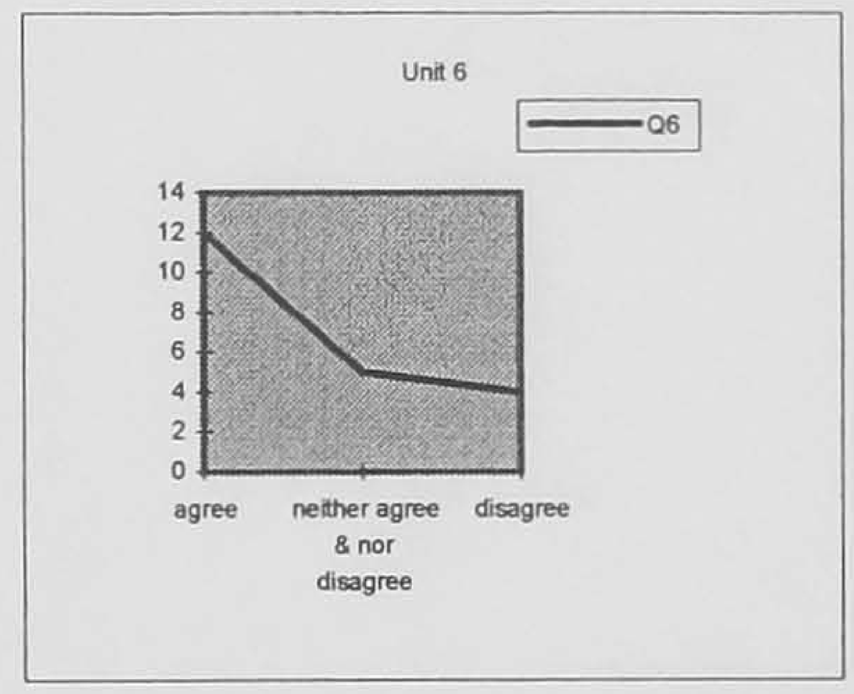
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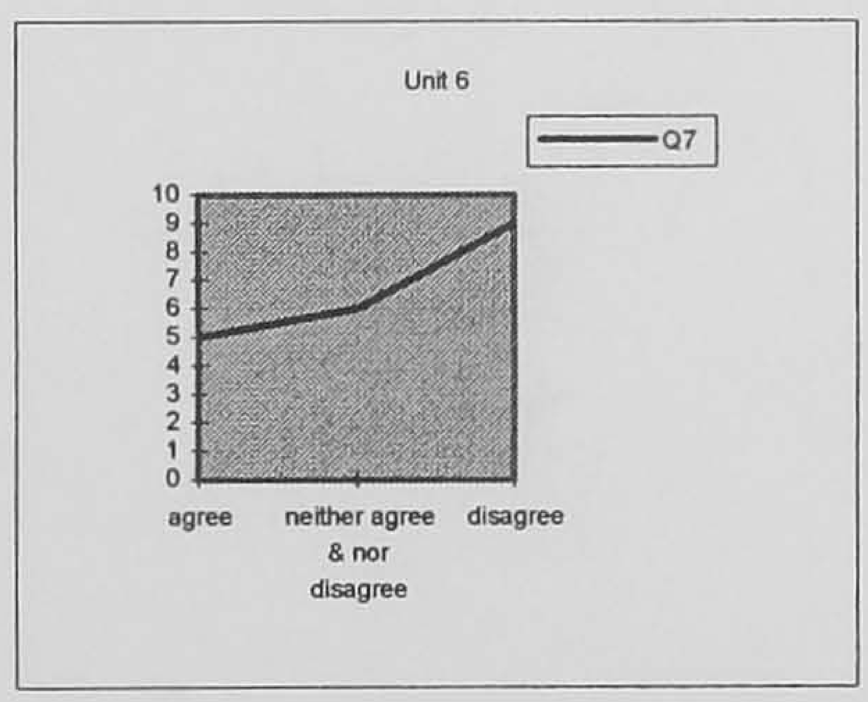
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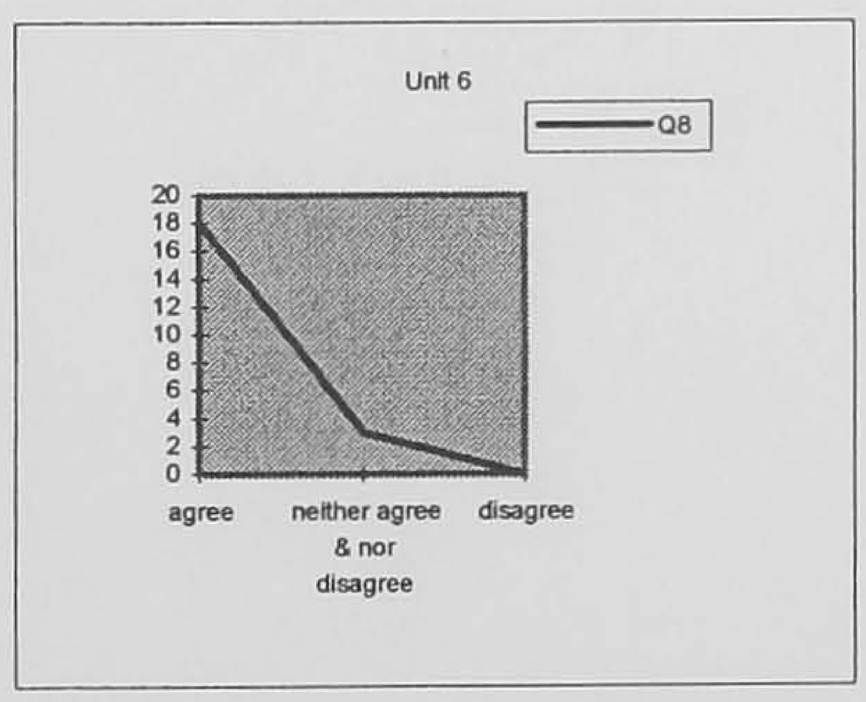
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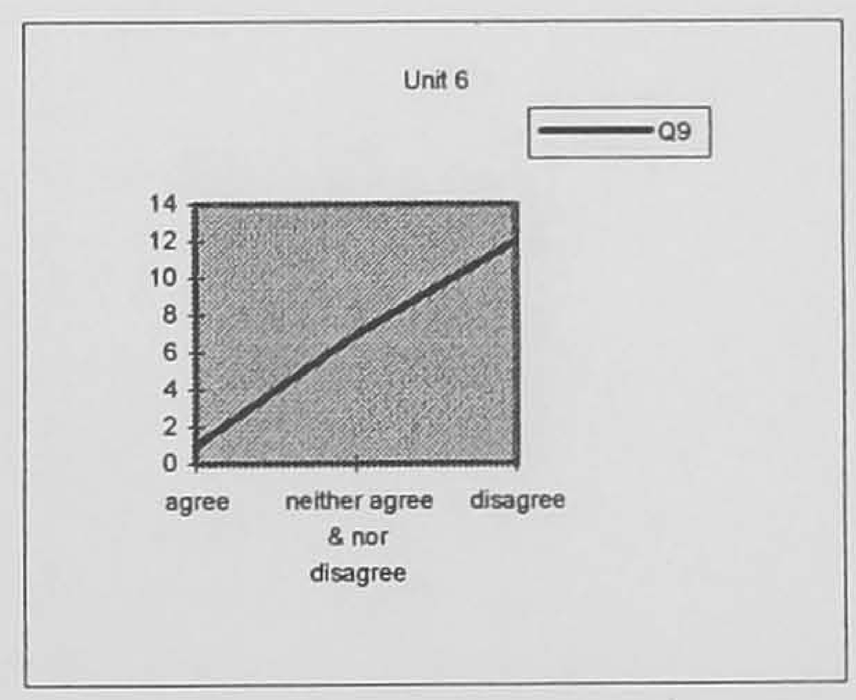
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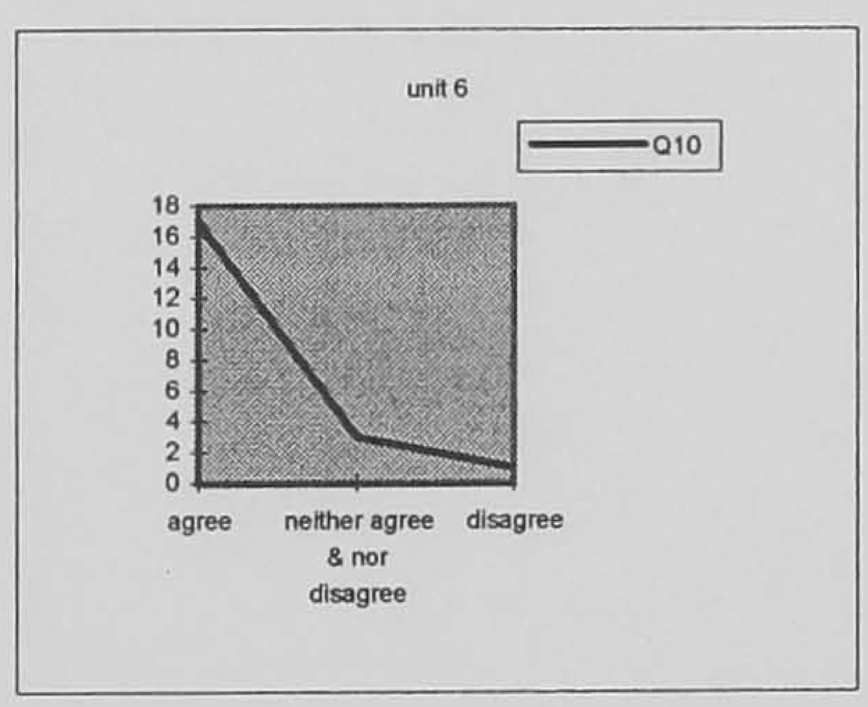
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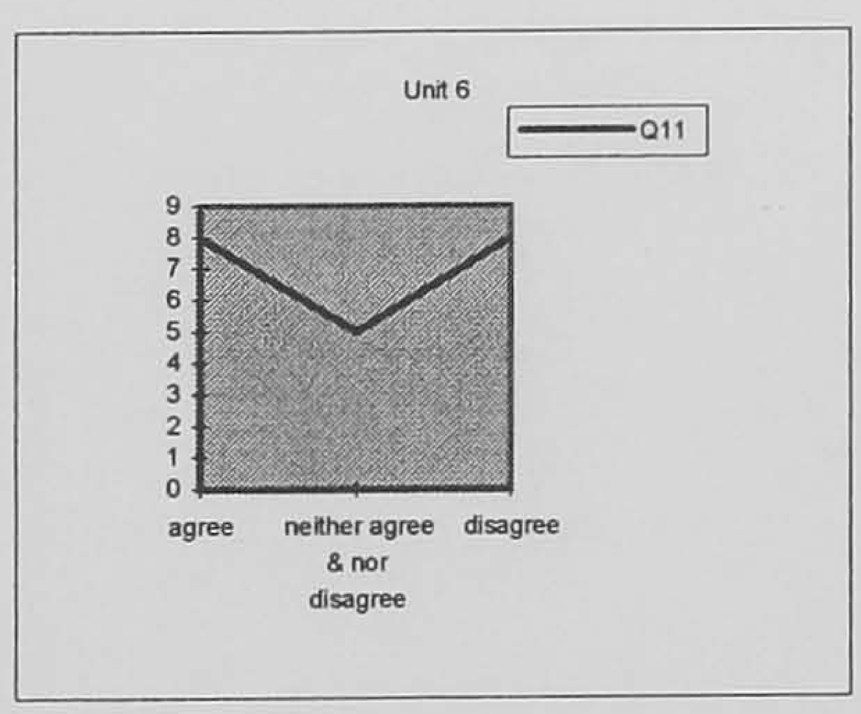
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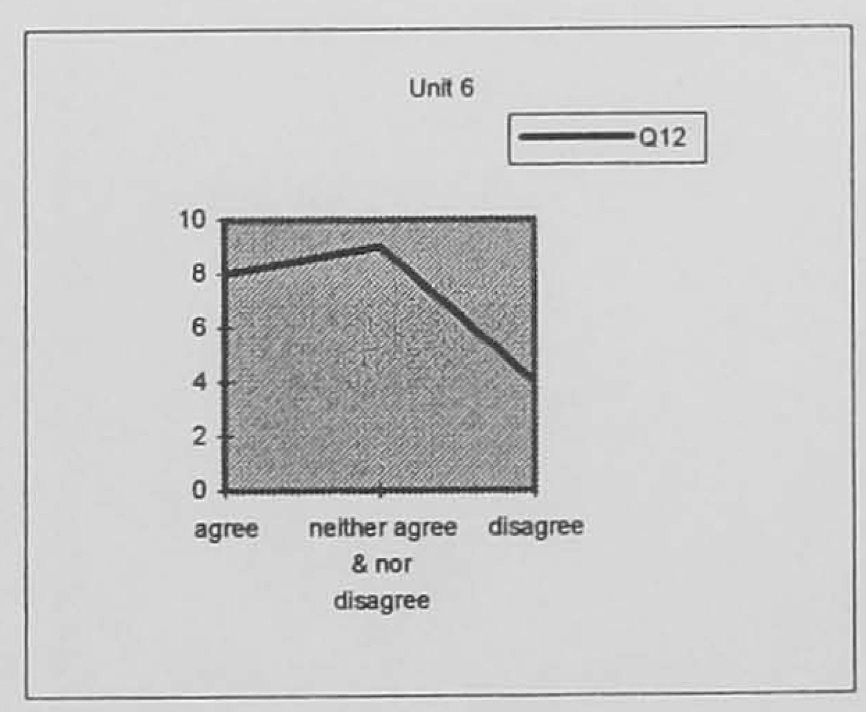
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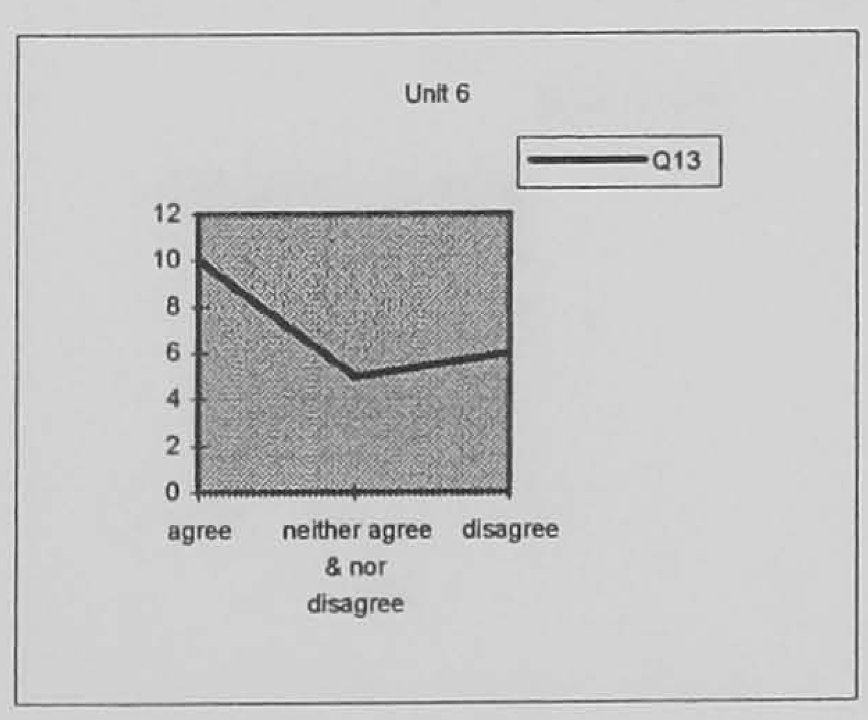
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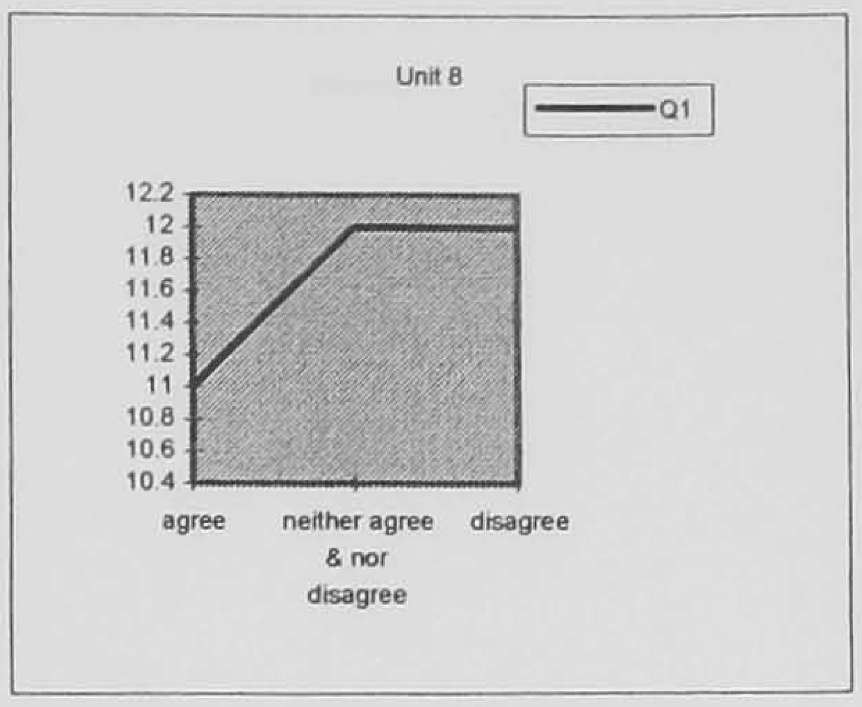
Unit 8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10.6
10.4
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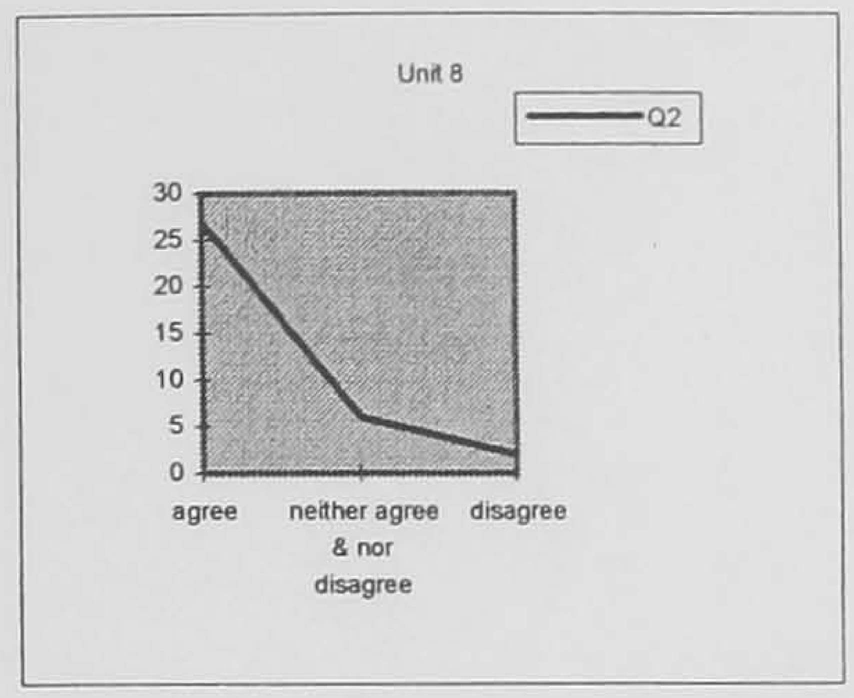
disagree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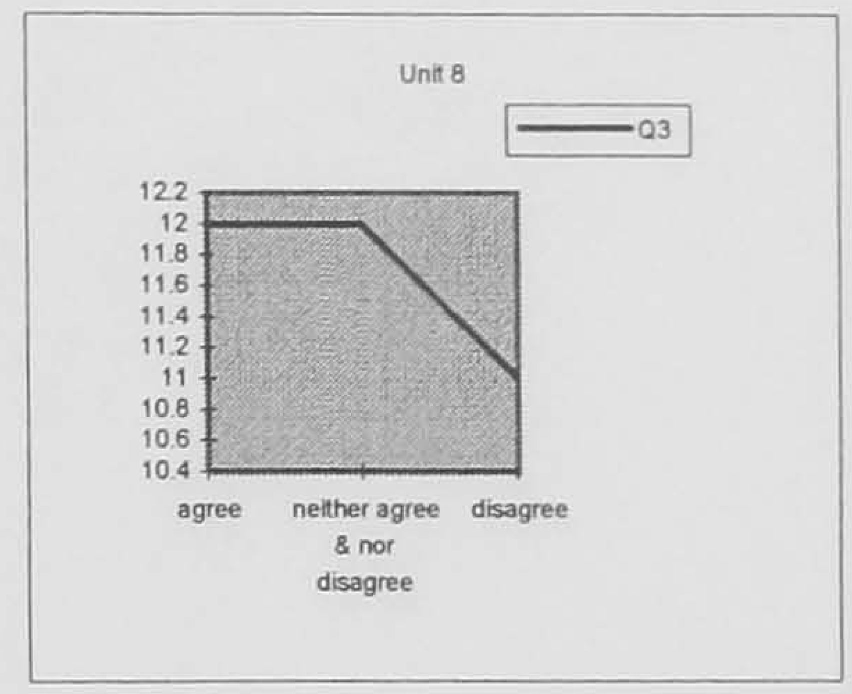
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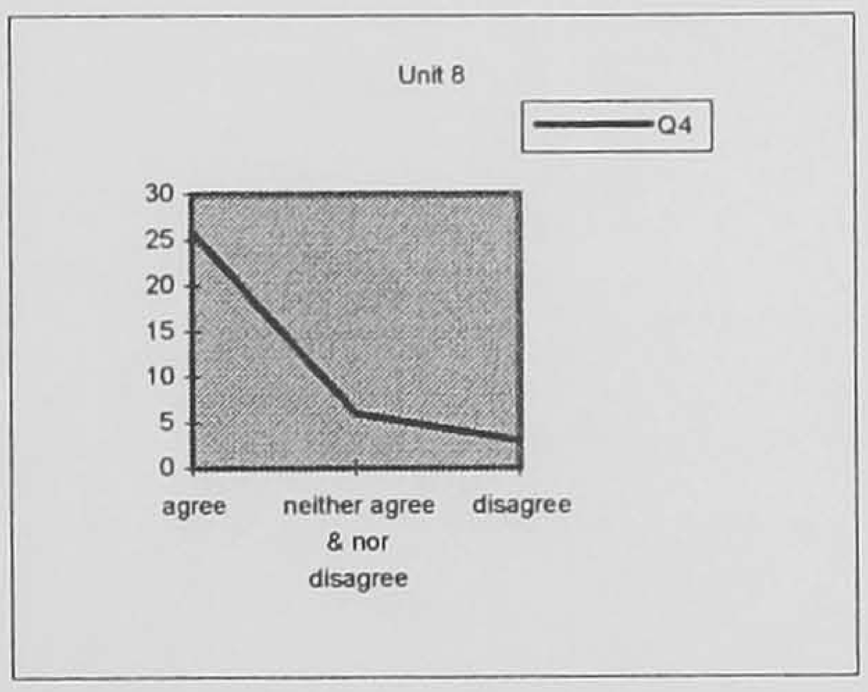
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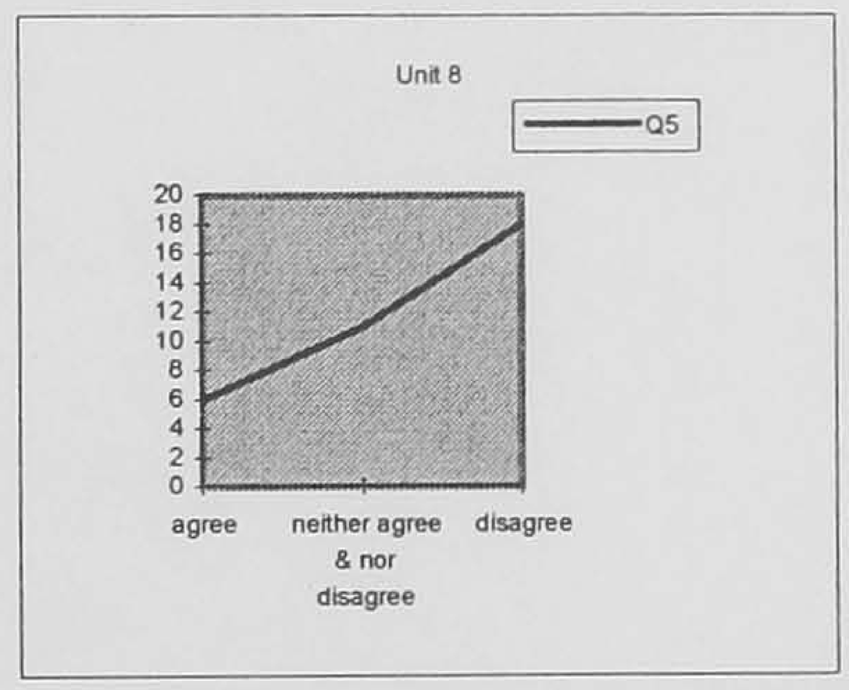
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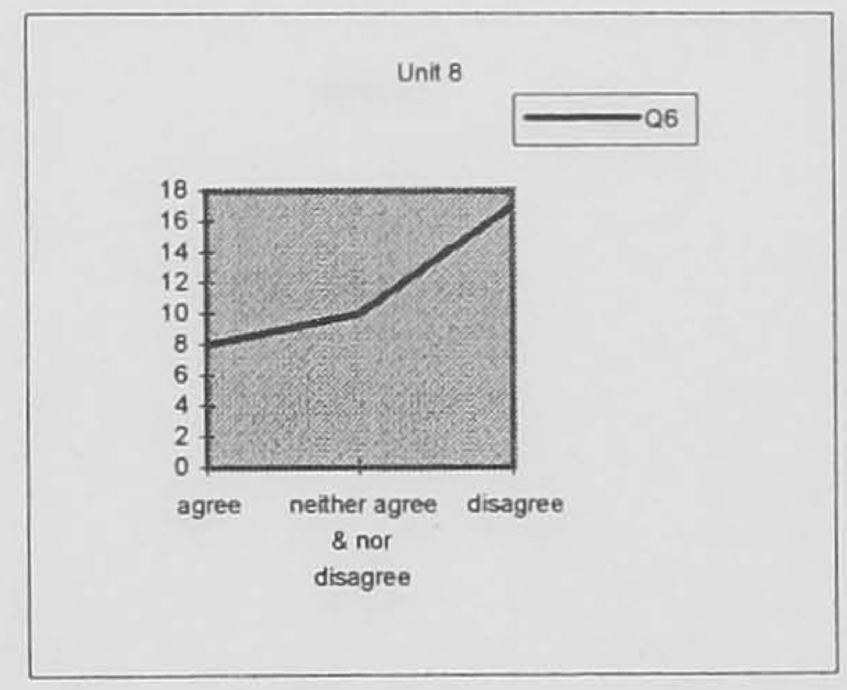
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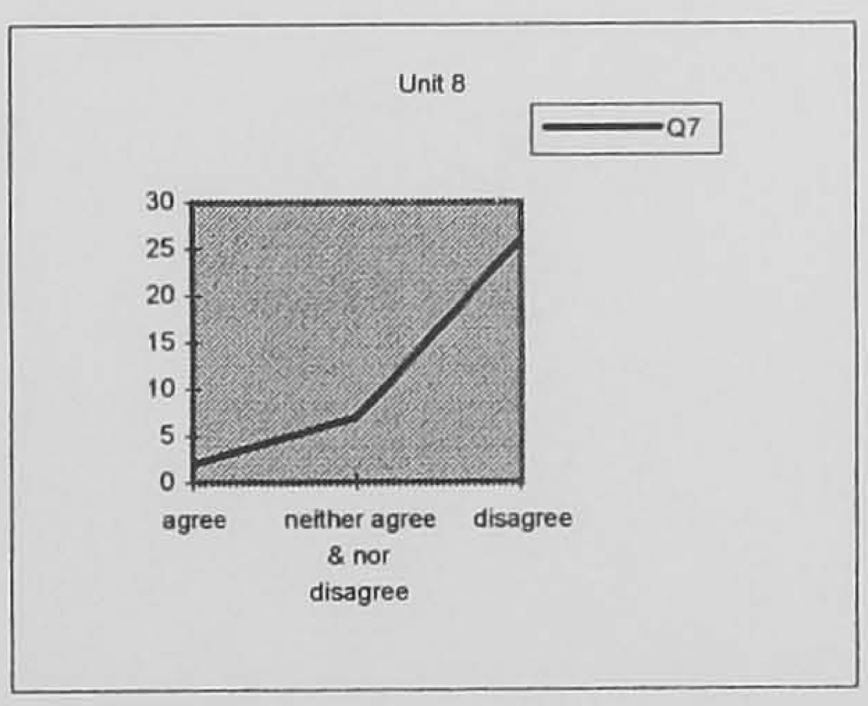
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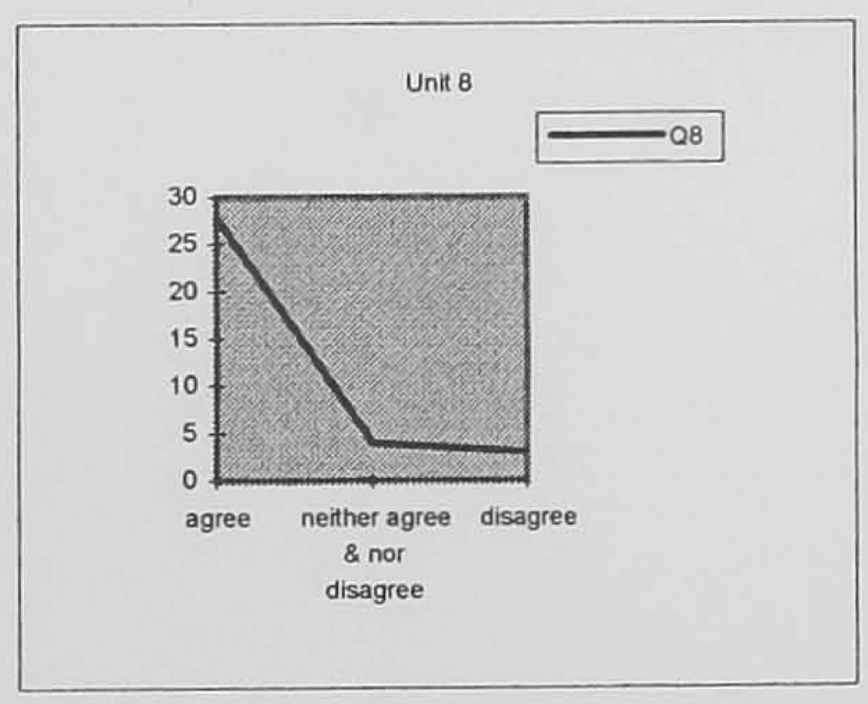
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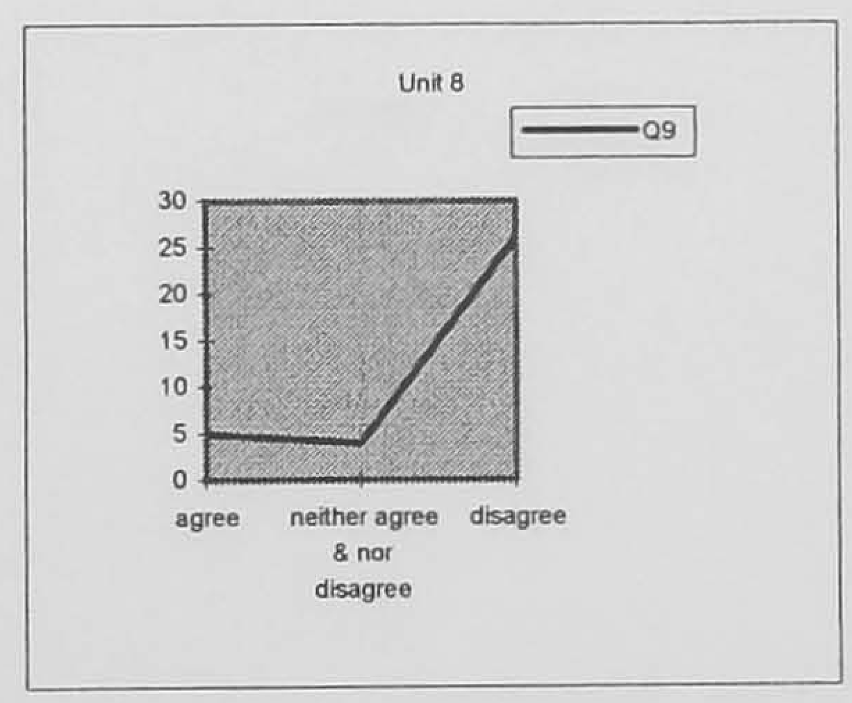
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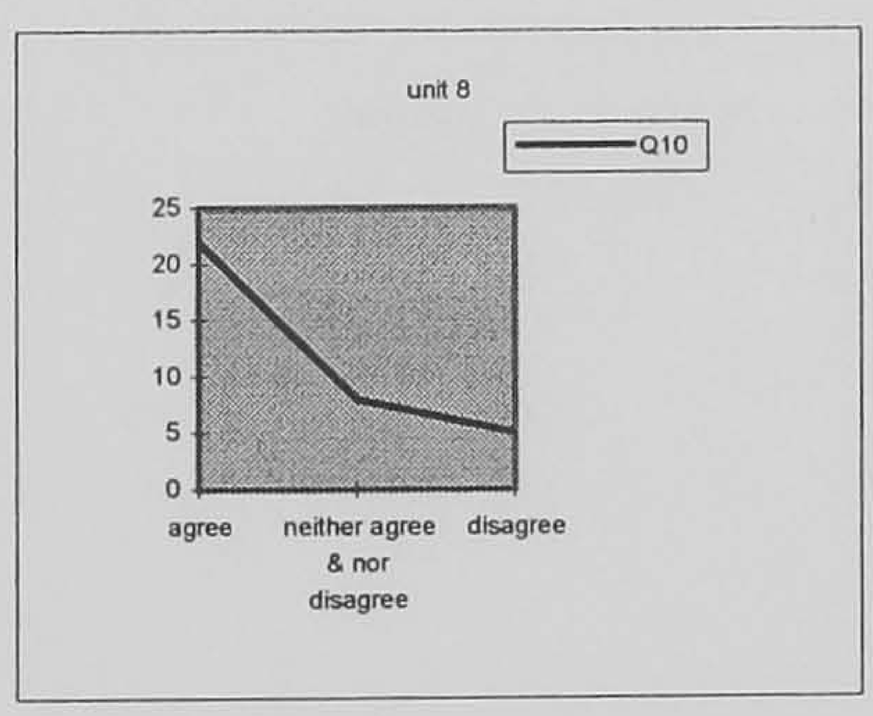
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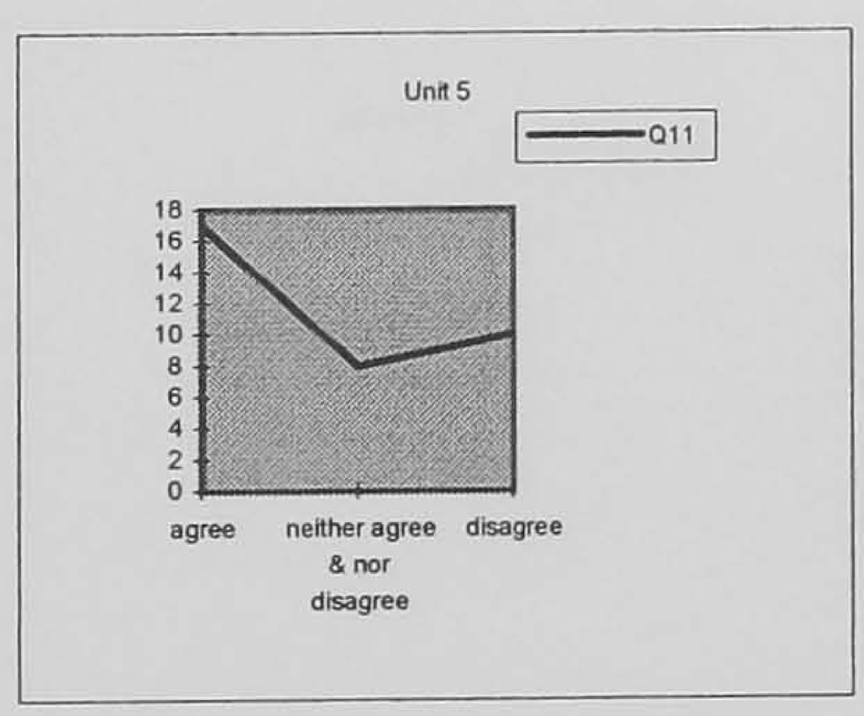
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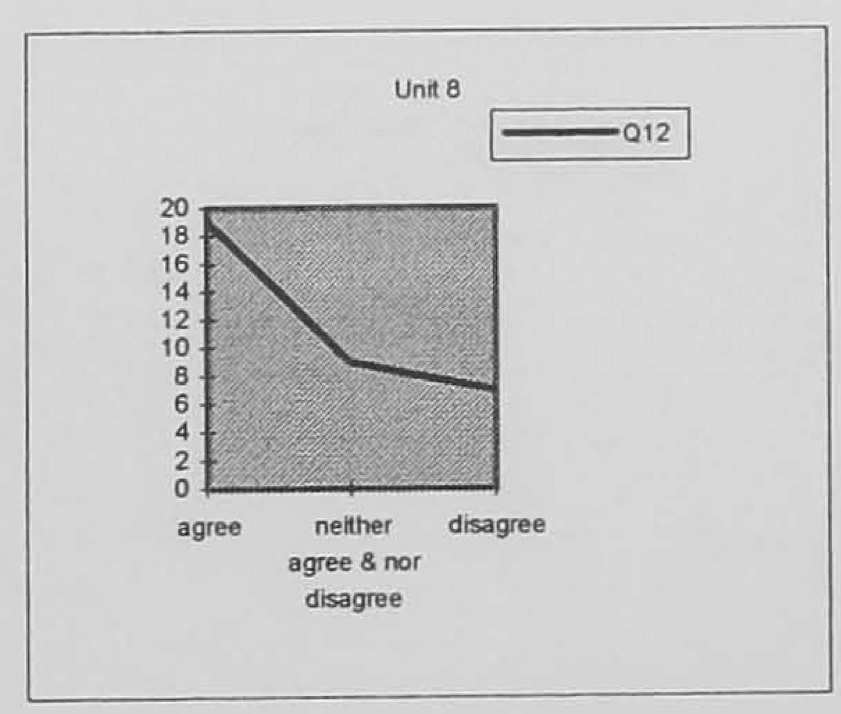
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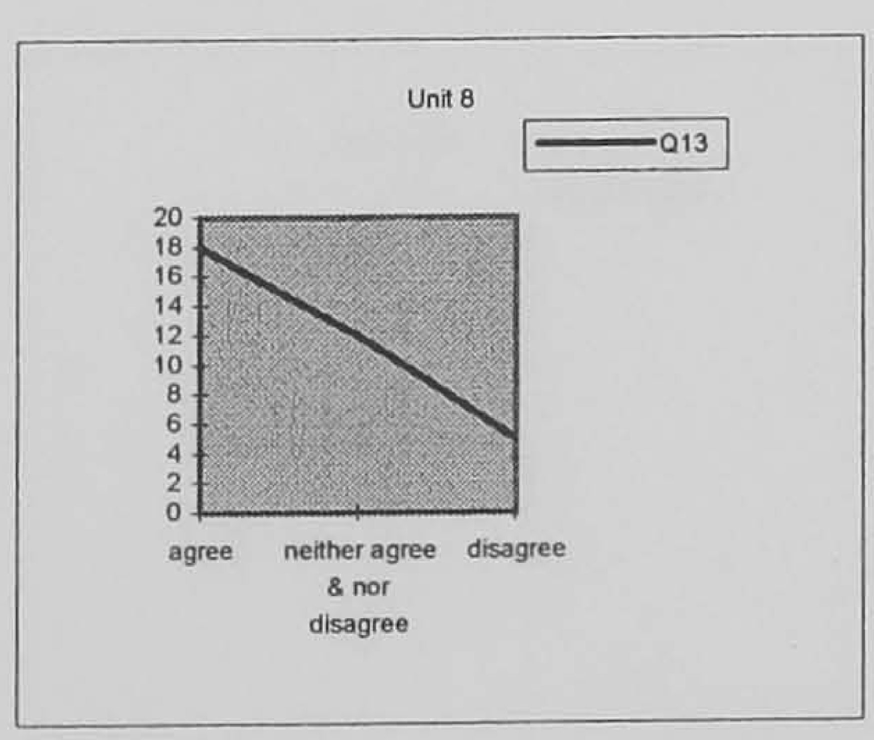
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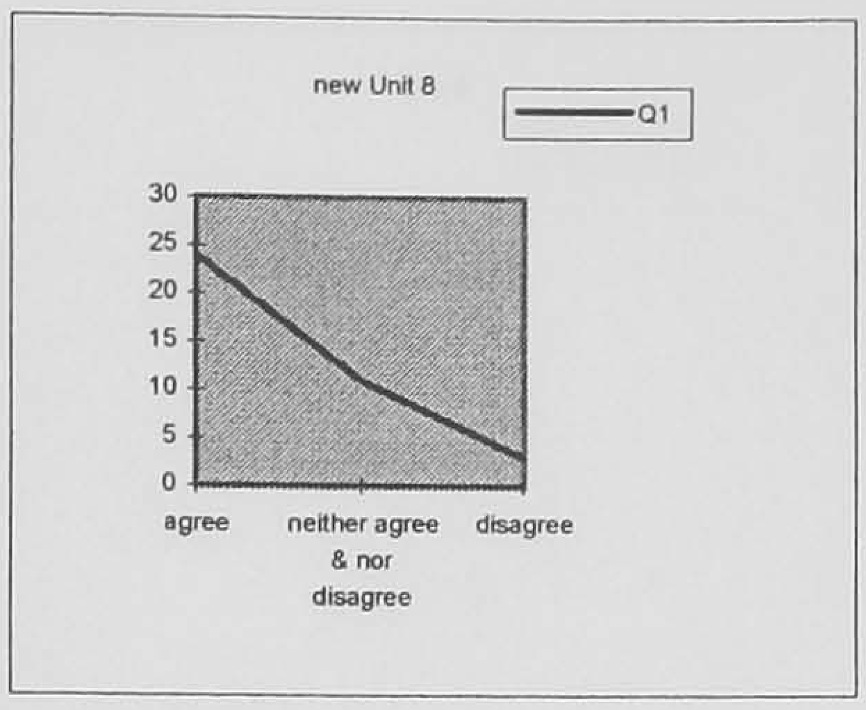
New Unit 8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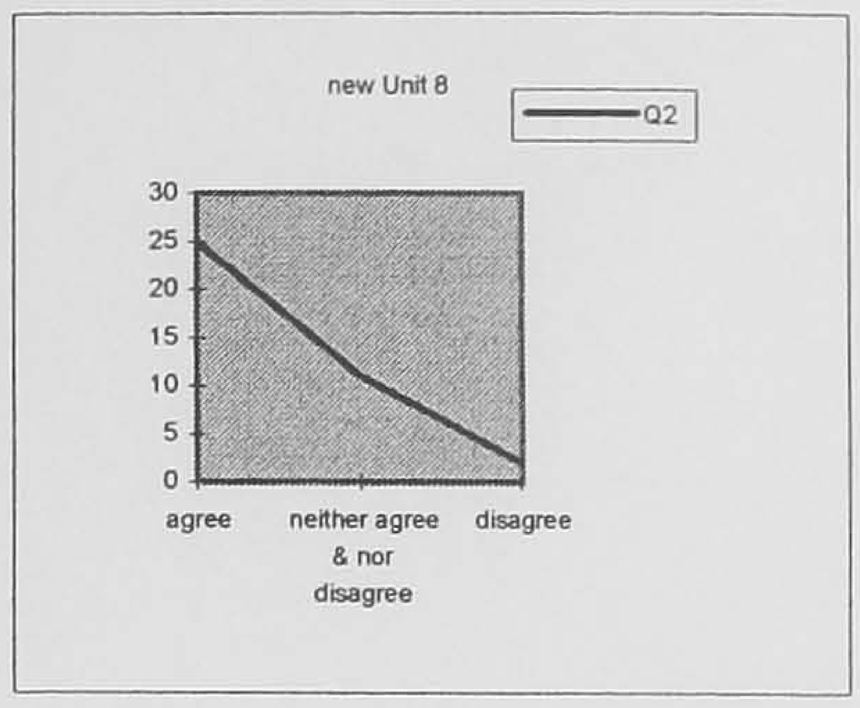
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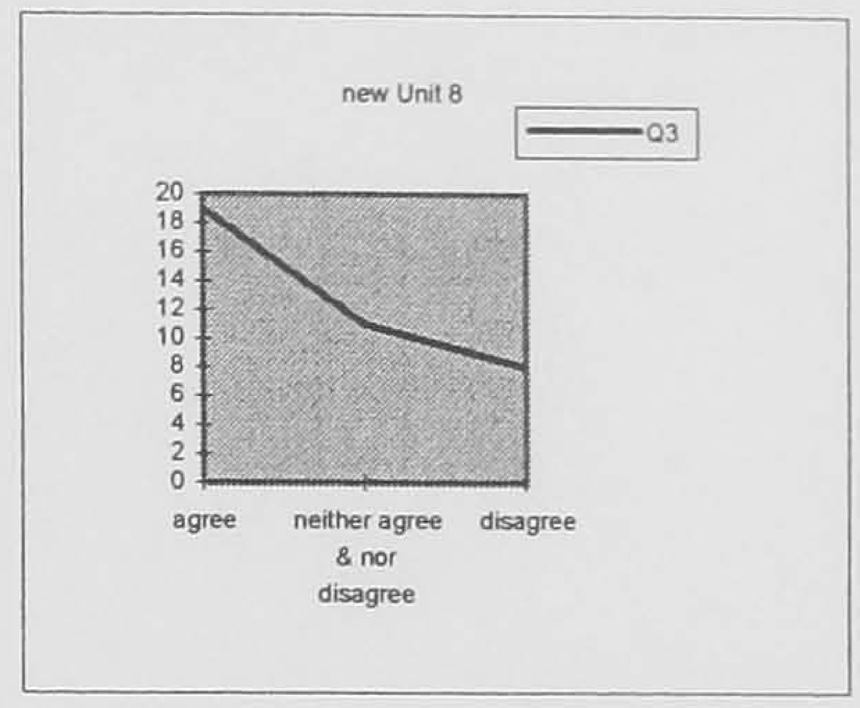
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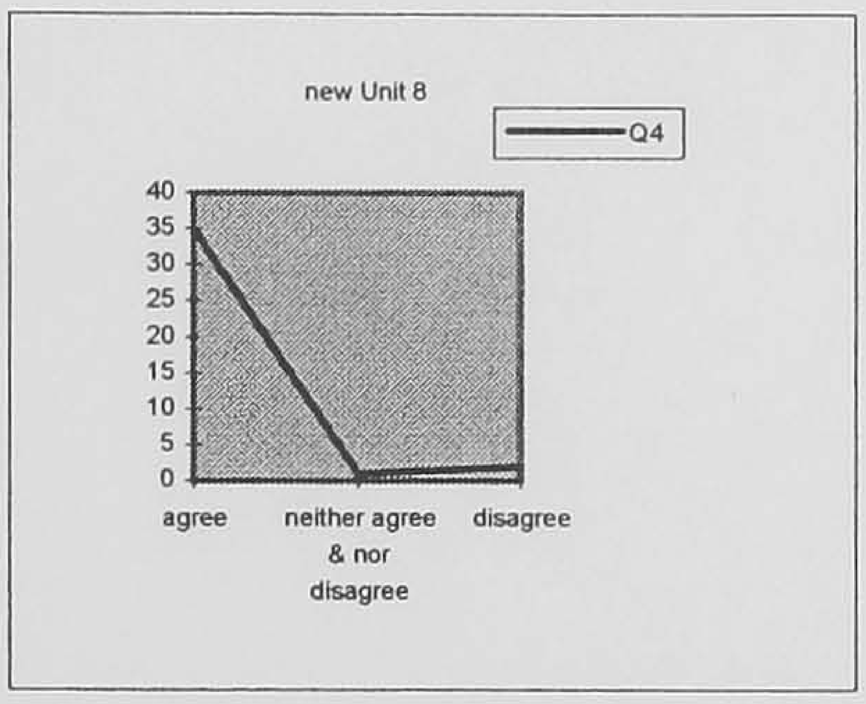
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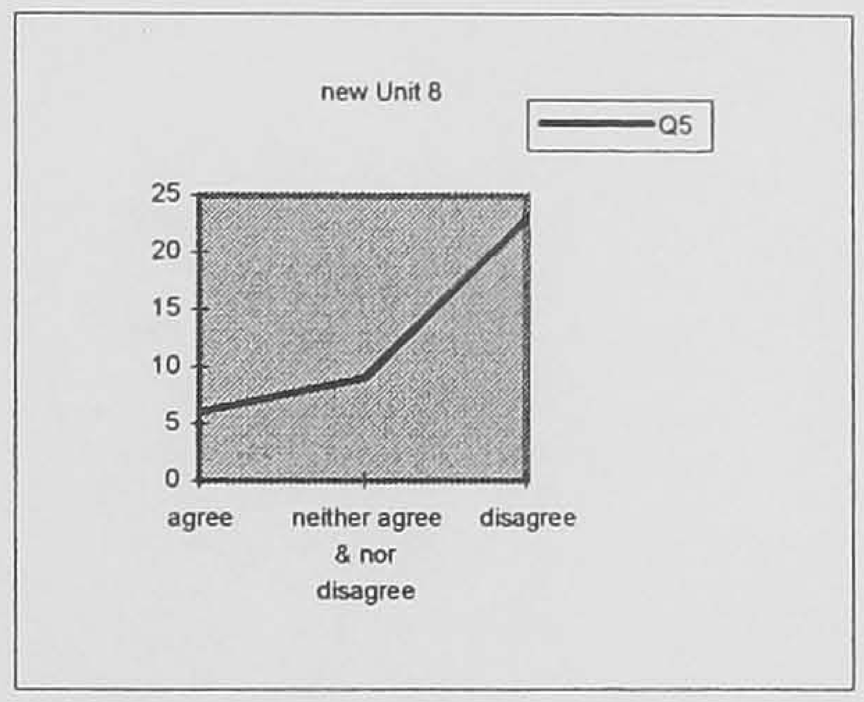
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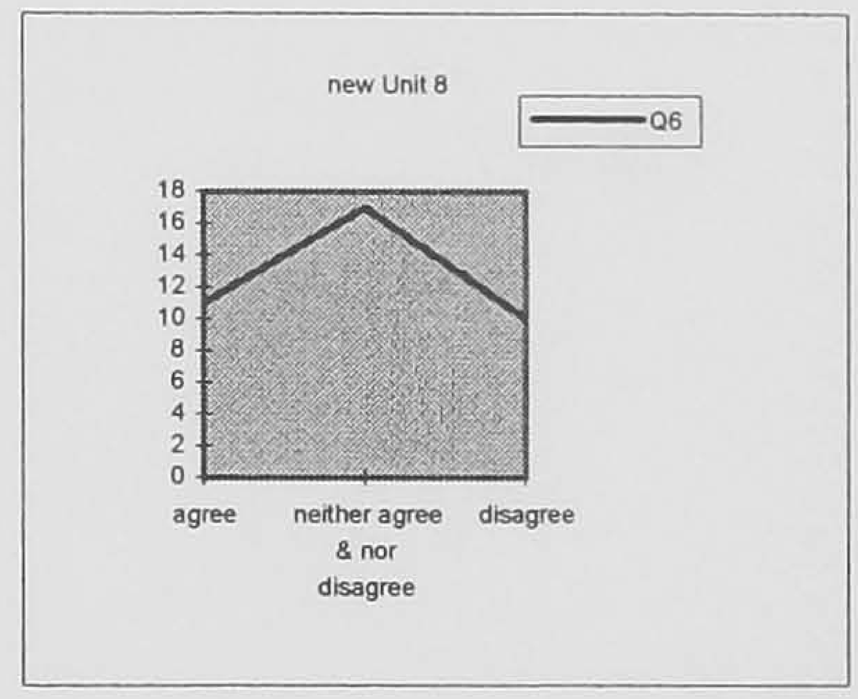
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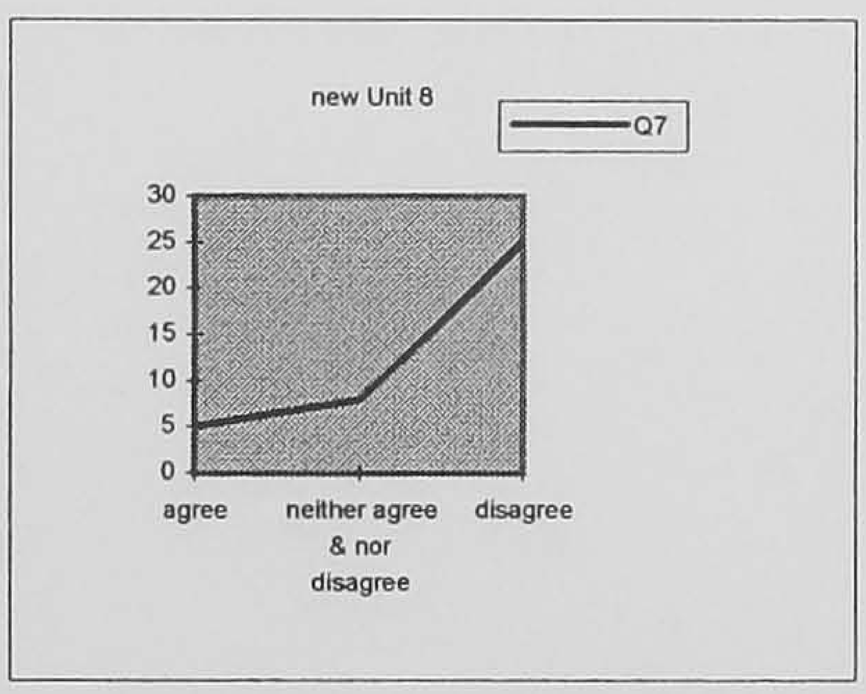
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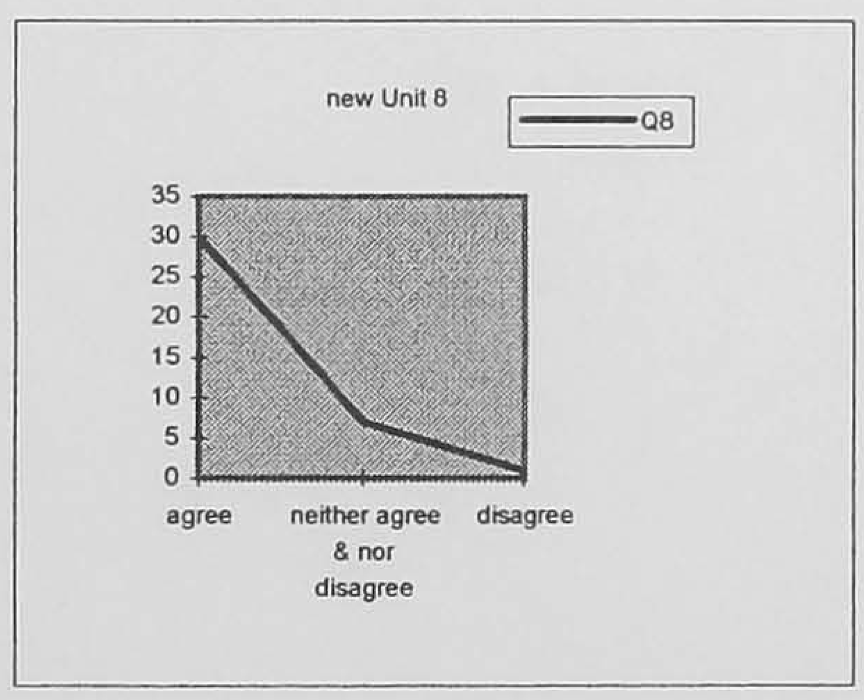
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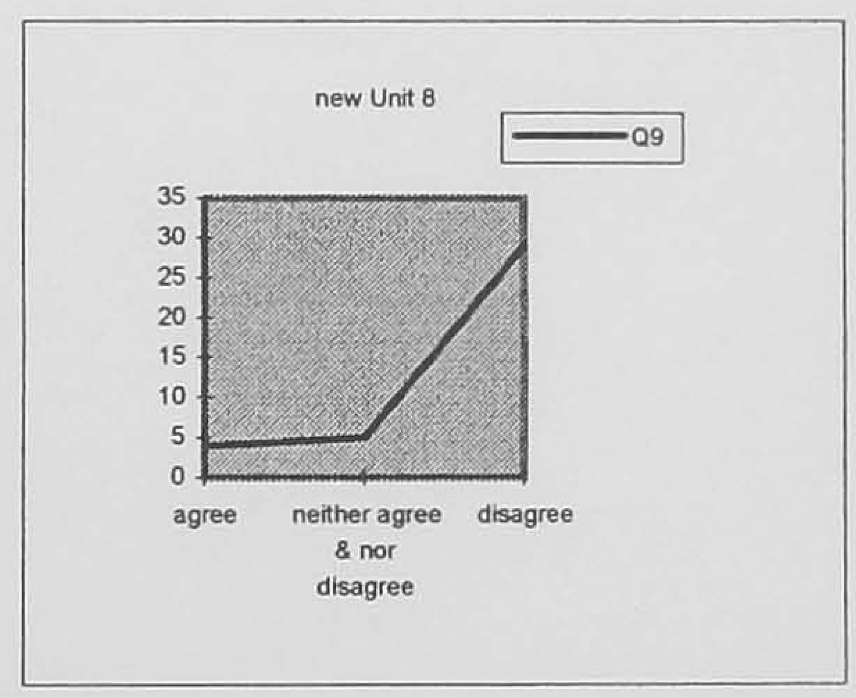
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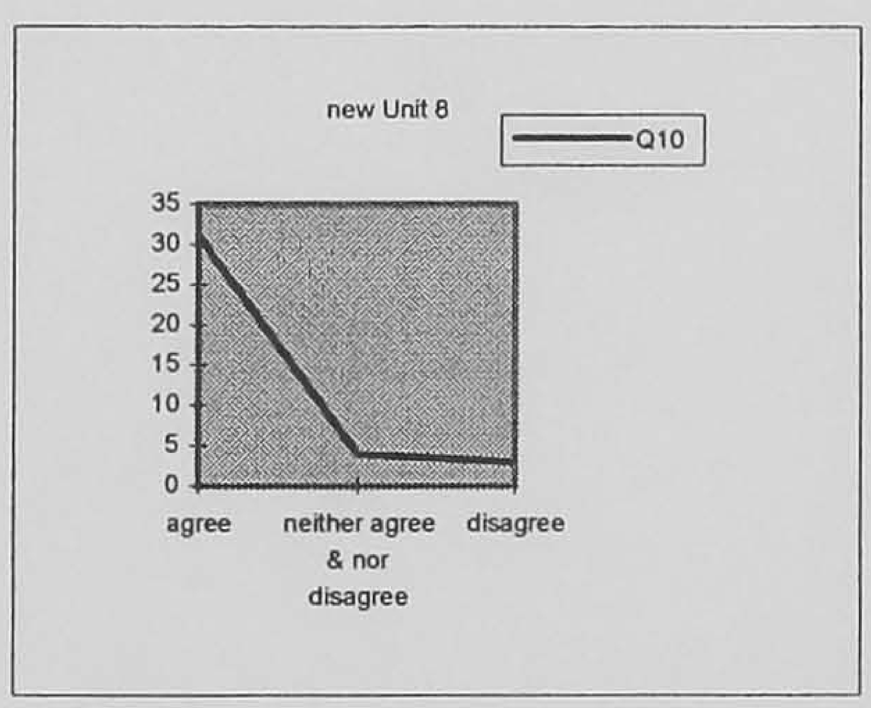
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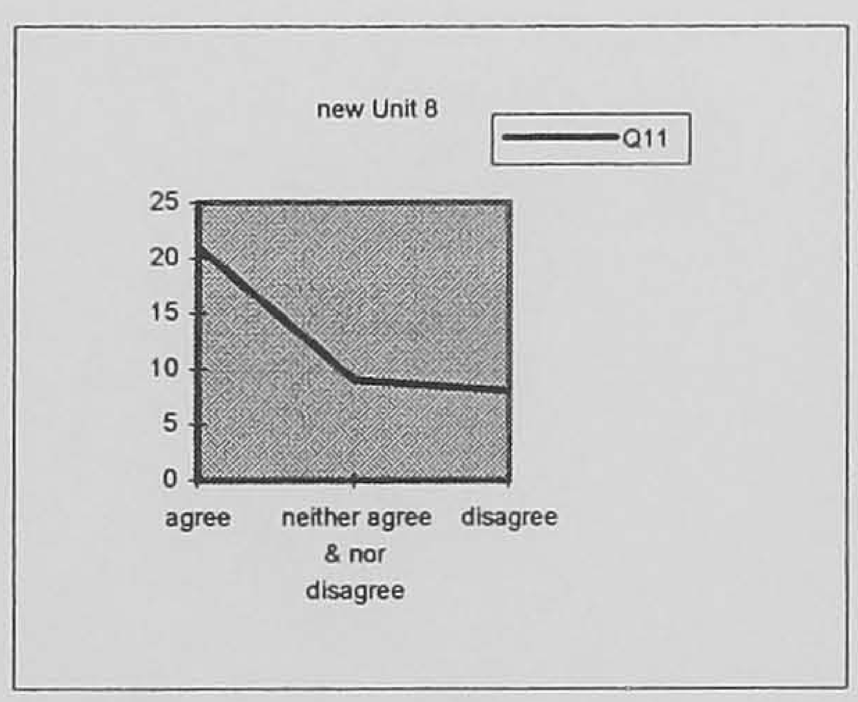
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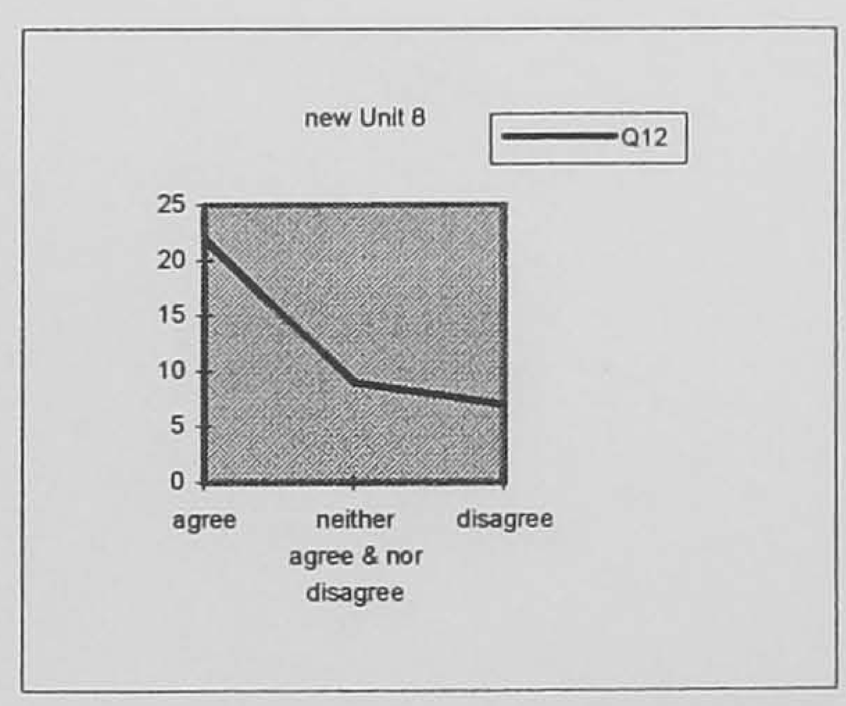
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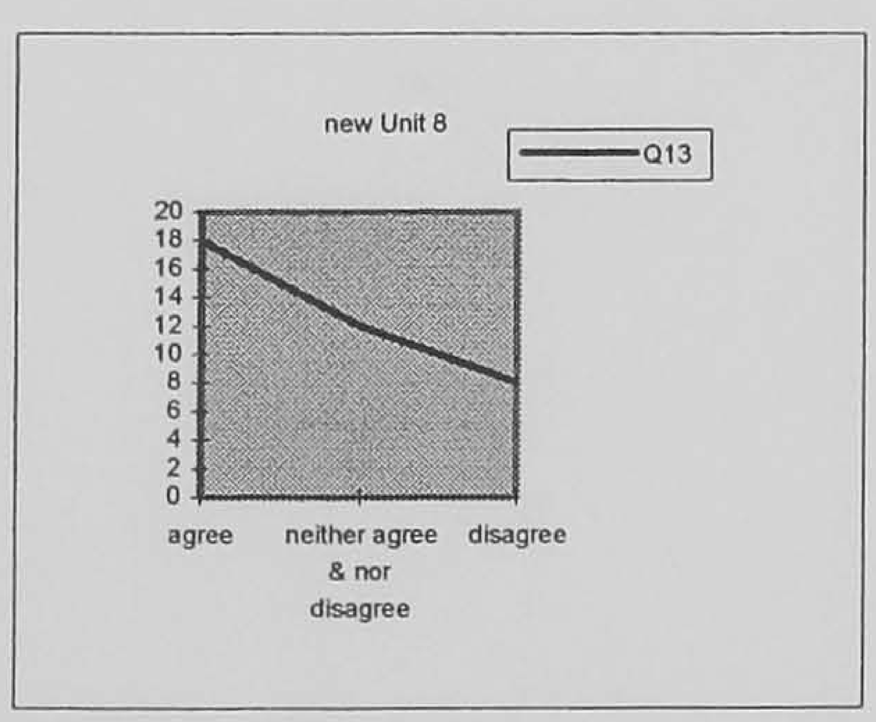
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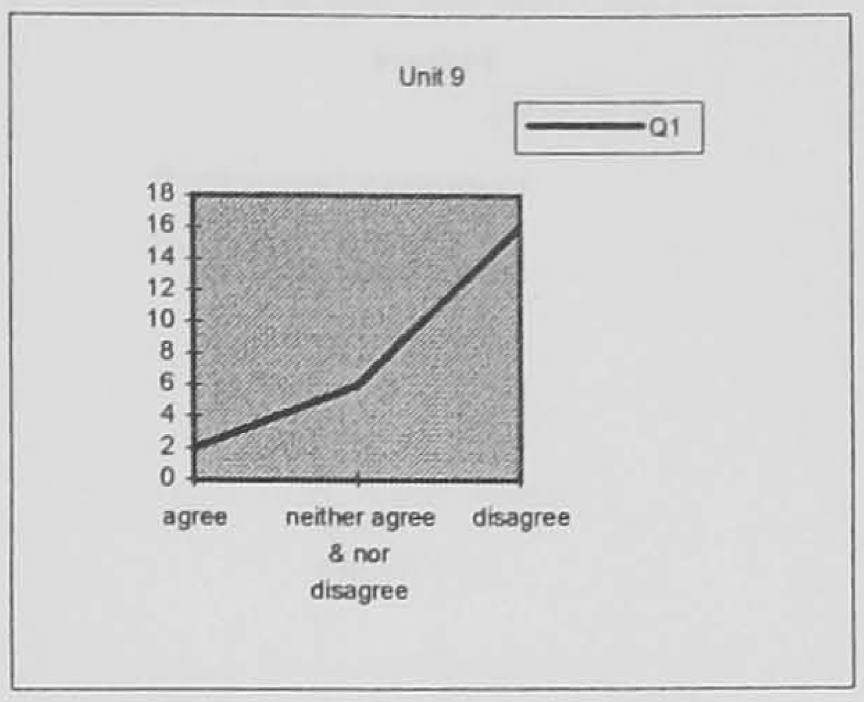
Unit 9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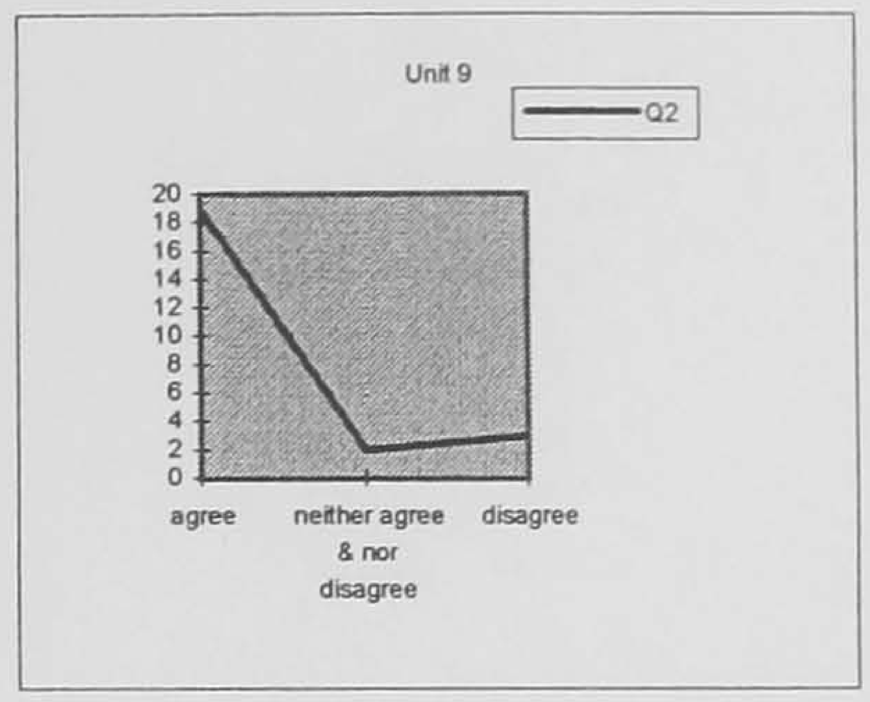
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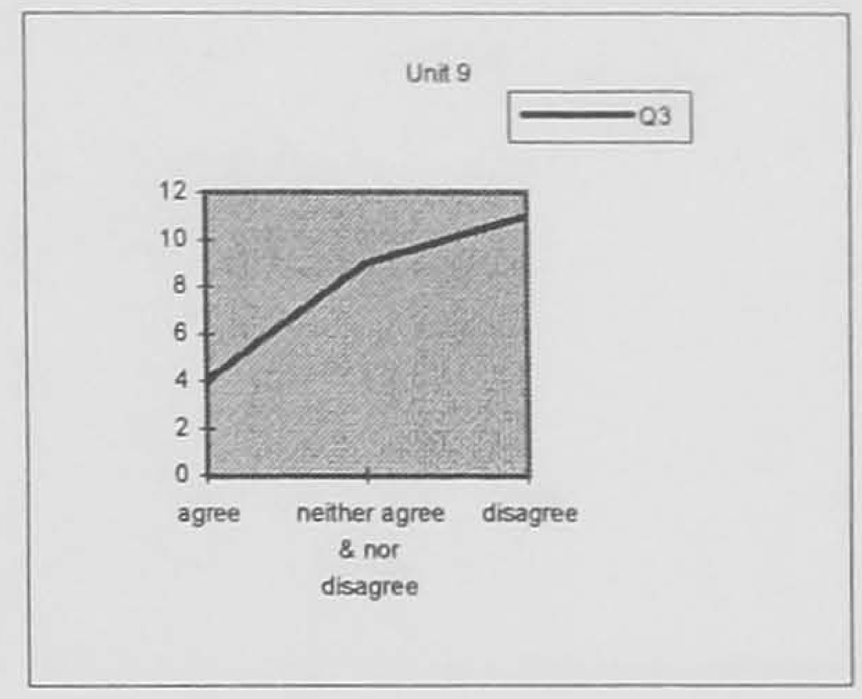
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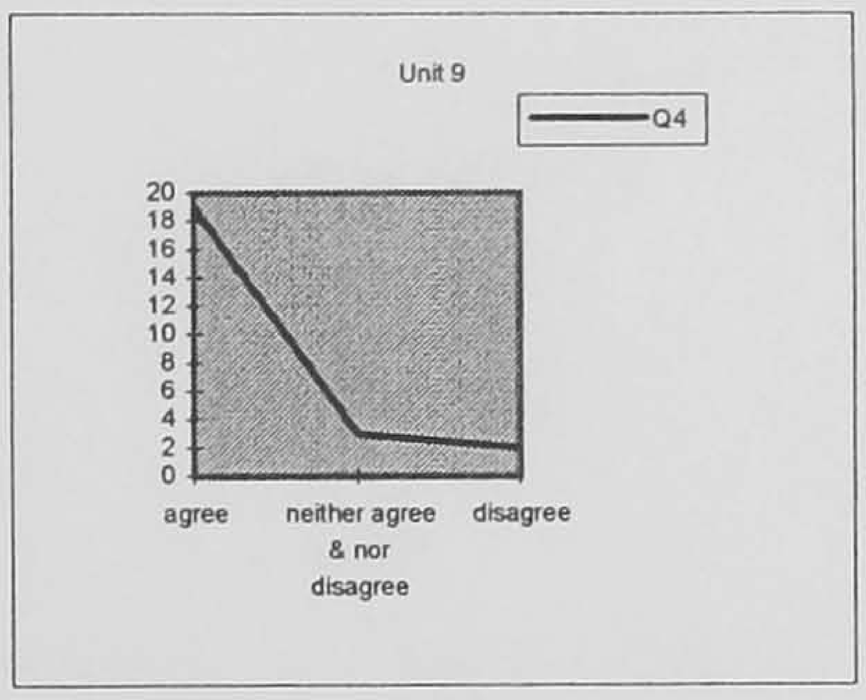
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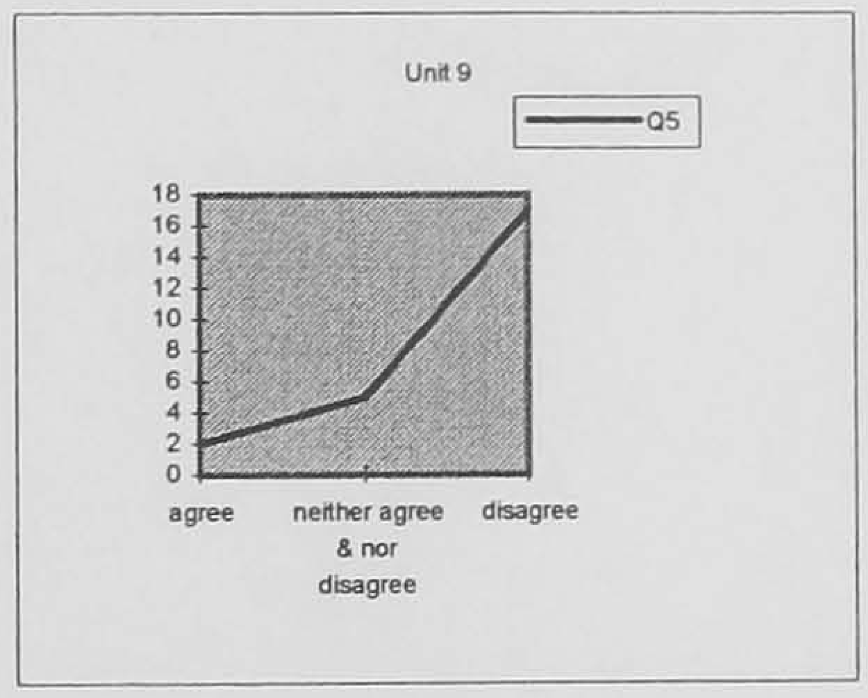
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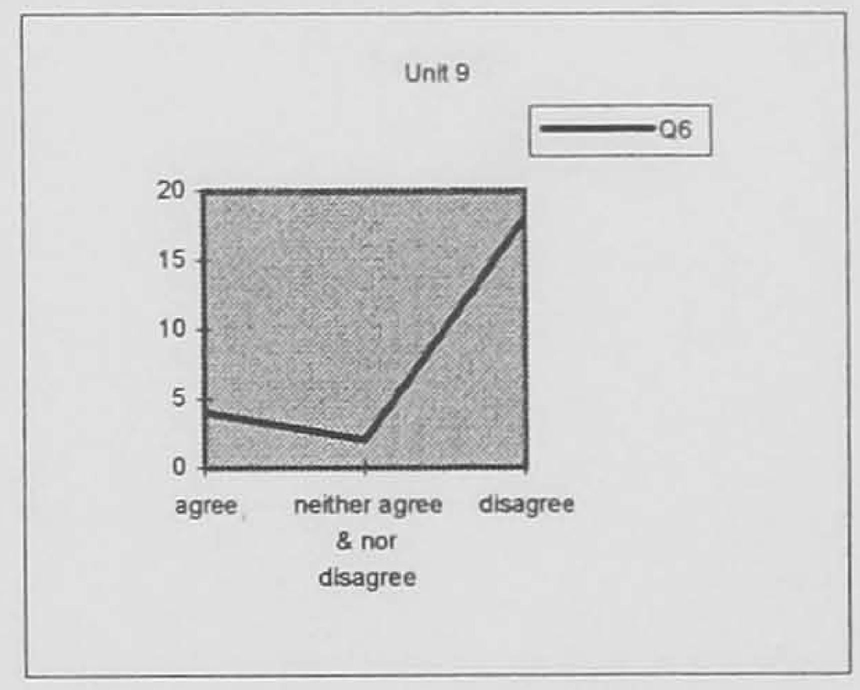
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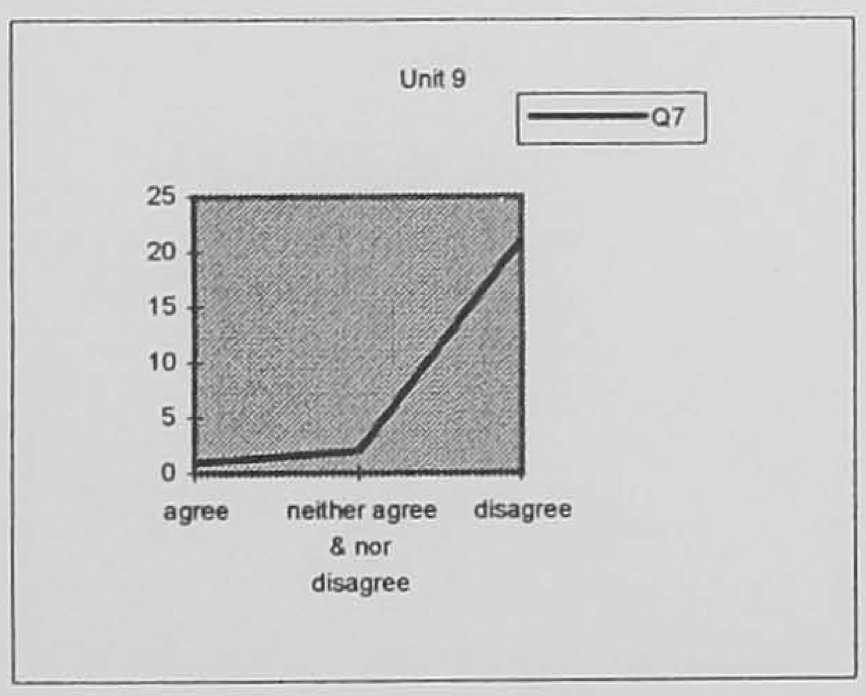
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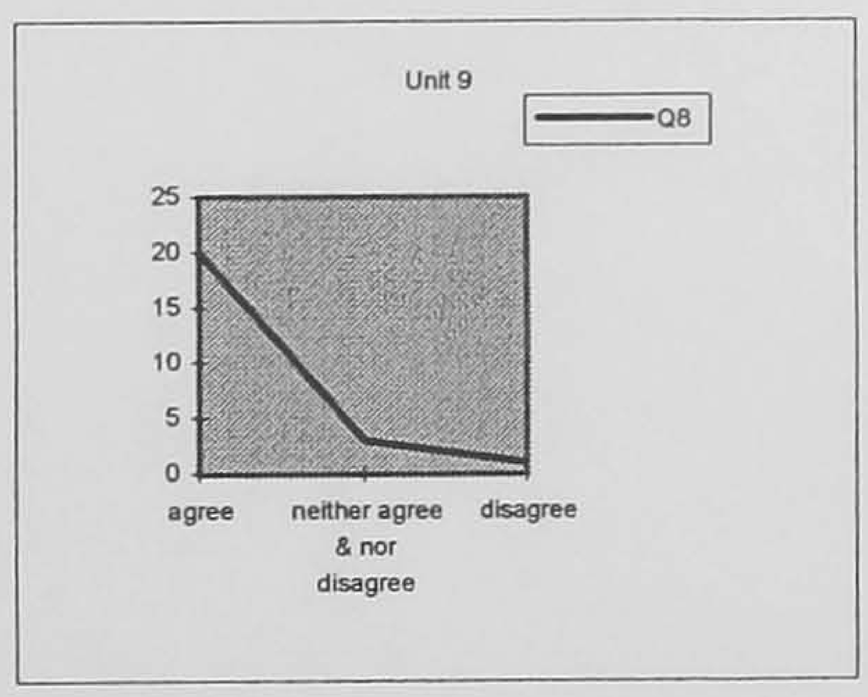
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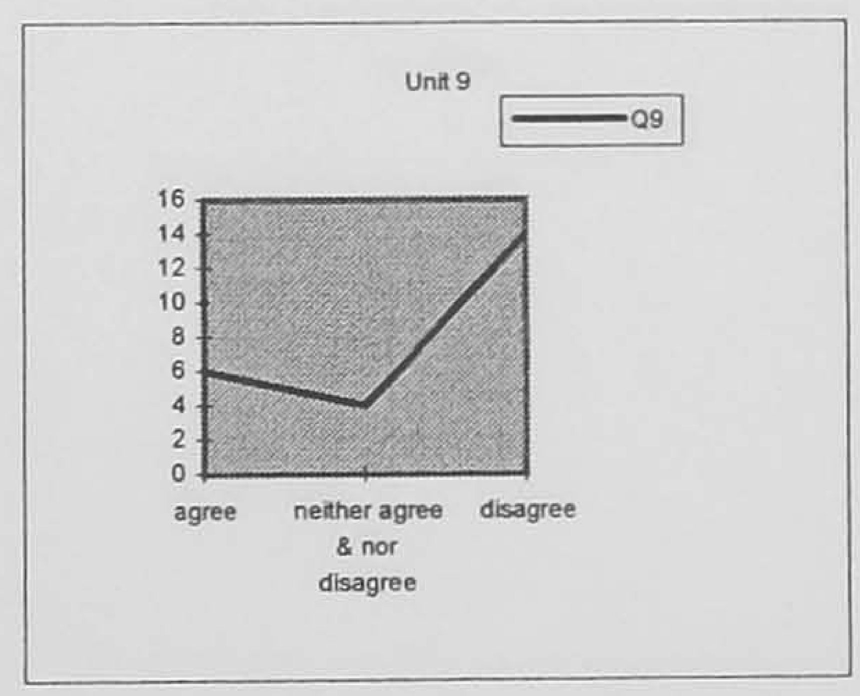
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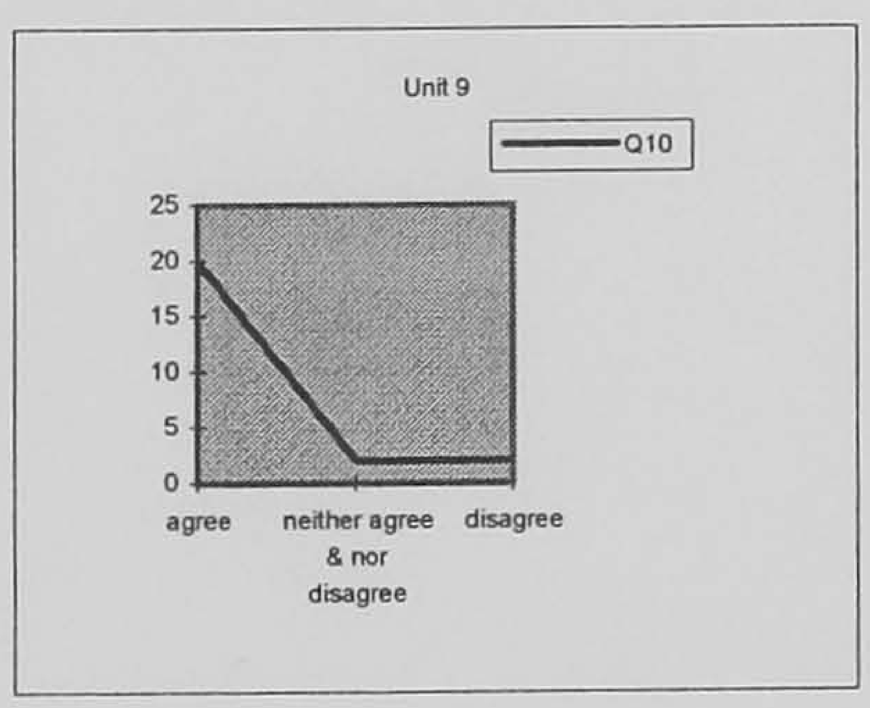
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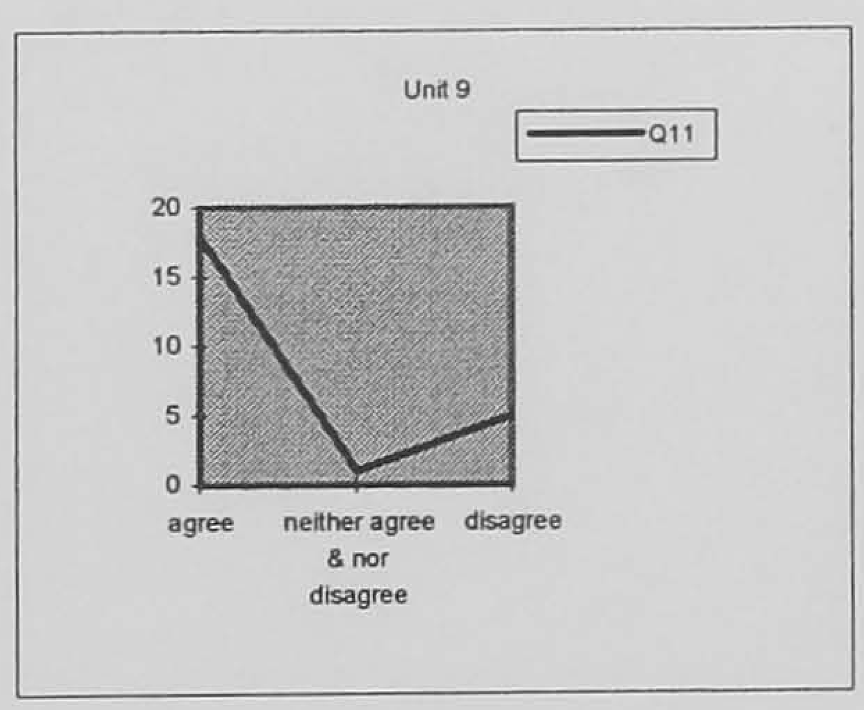
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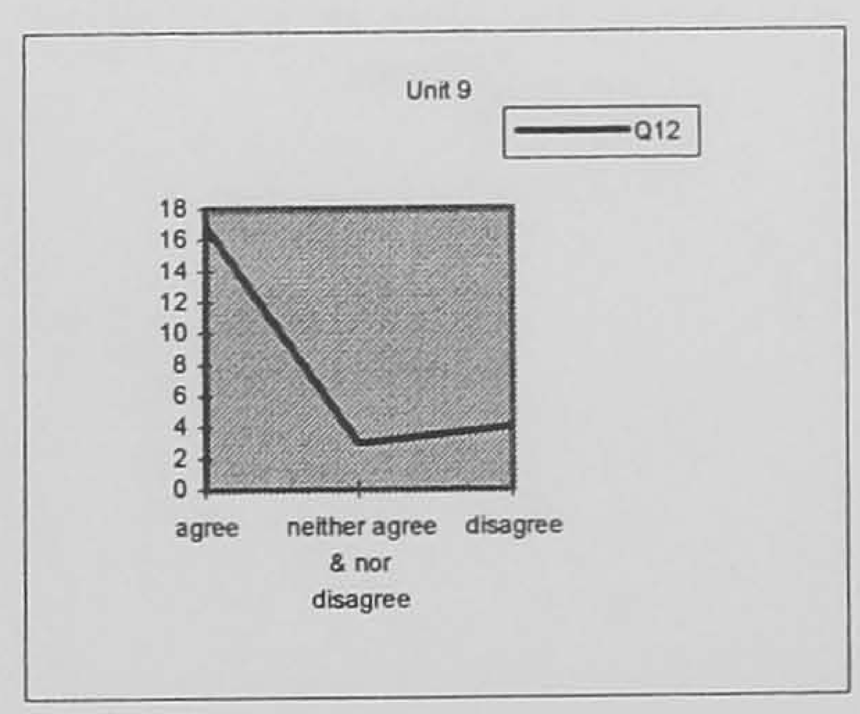
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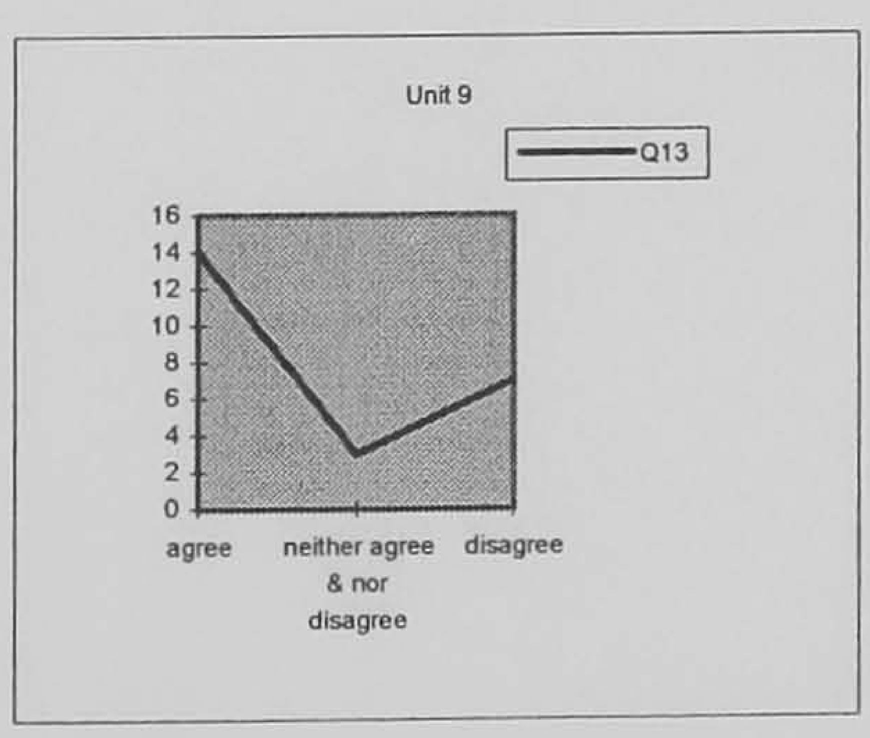
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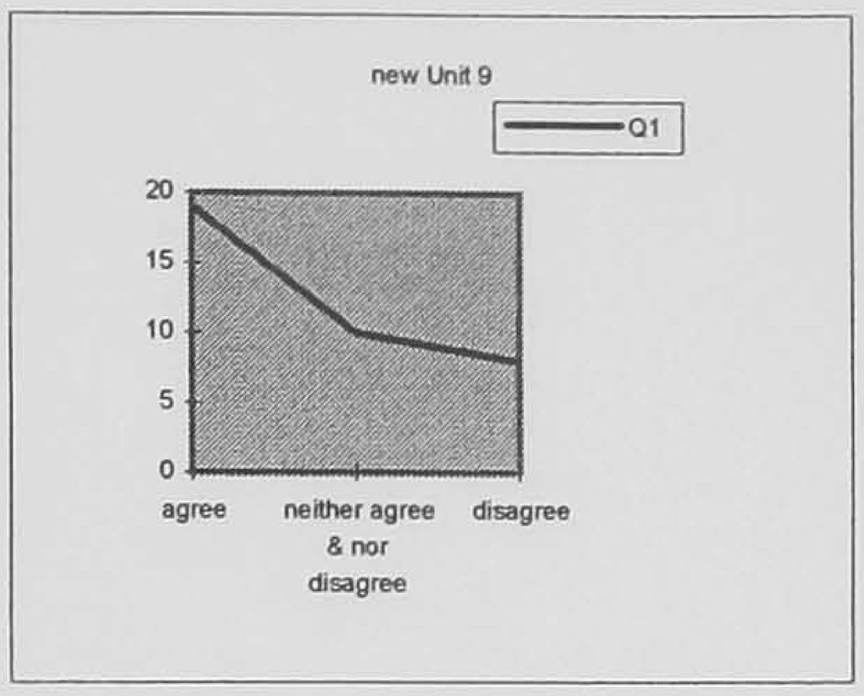
New Unit 9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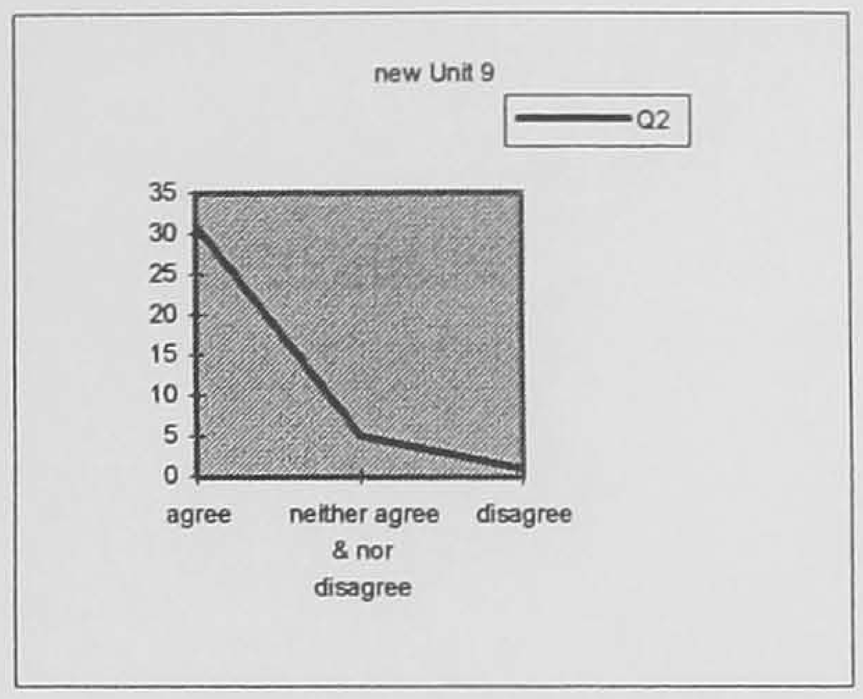
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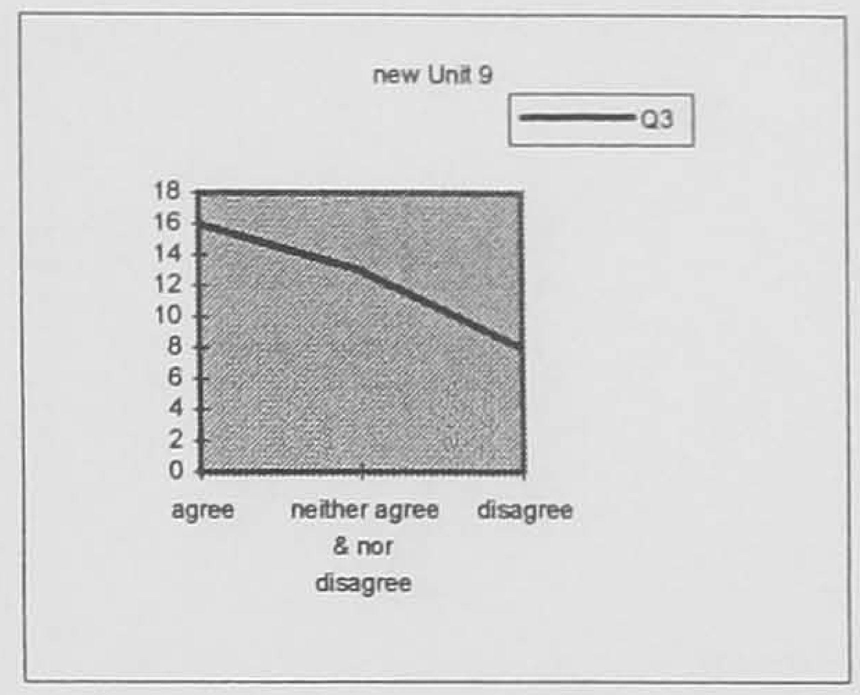
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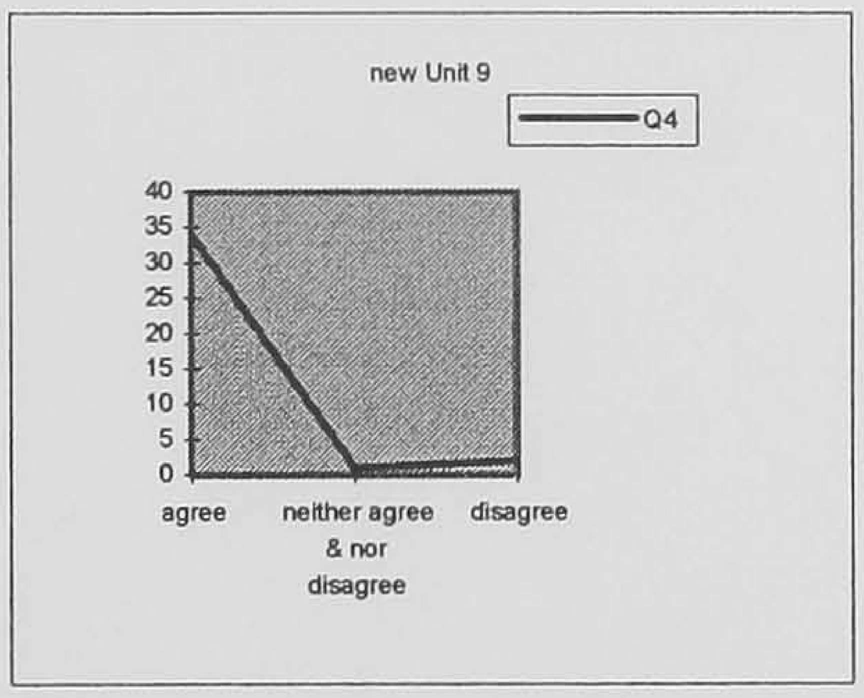
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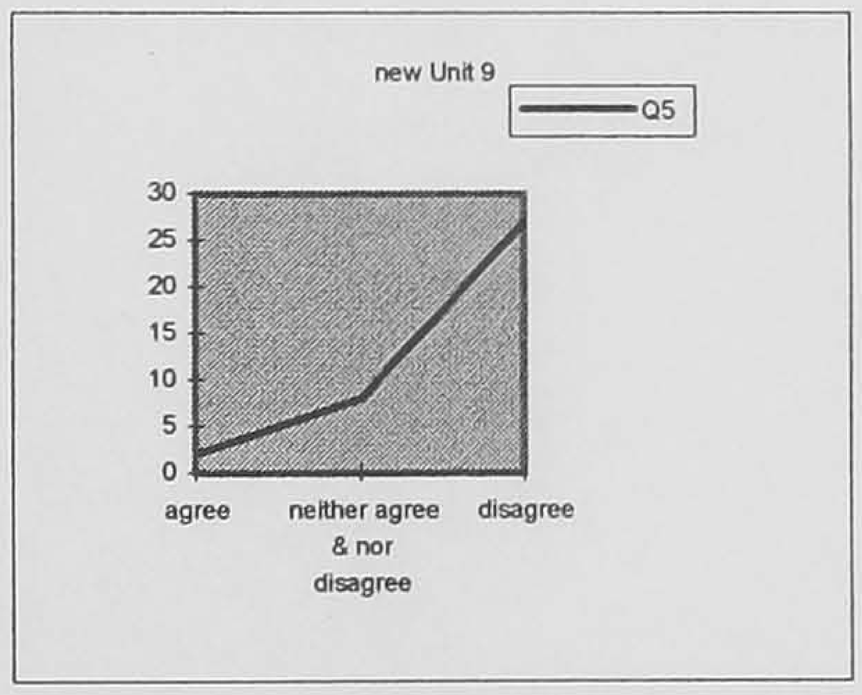
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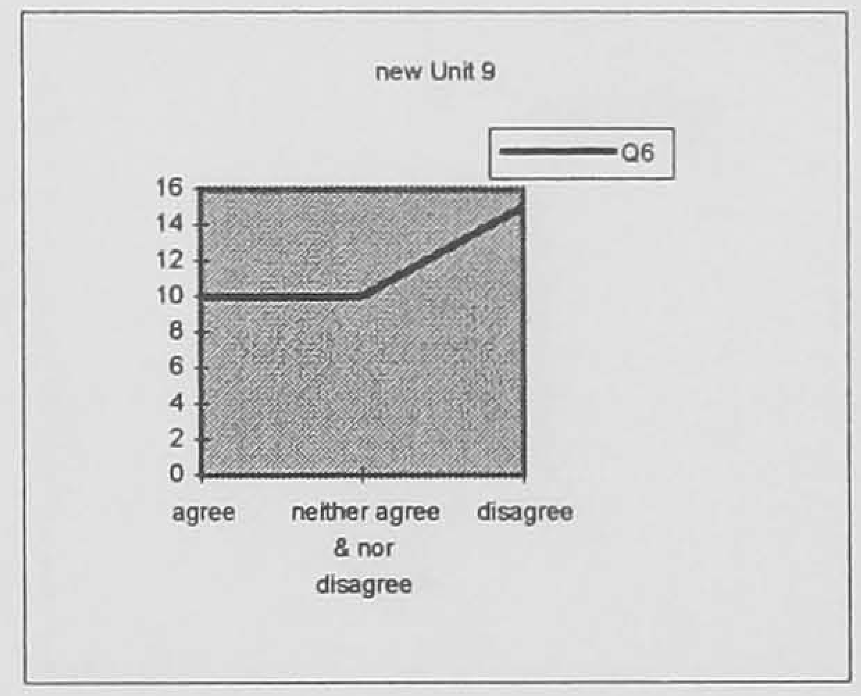
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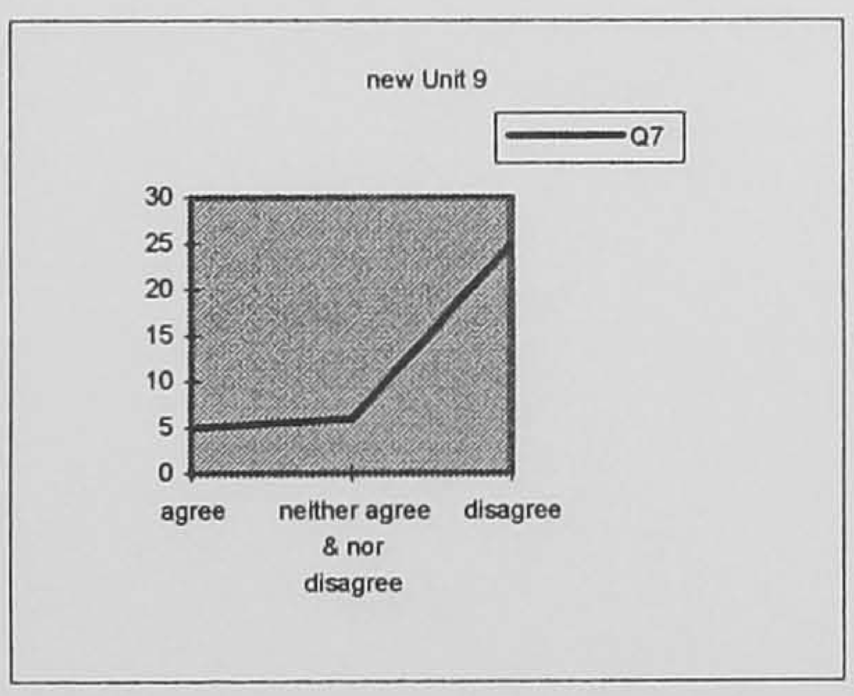
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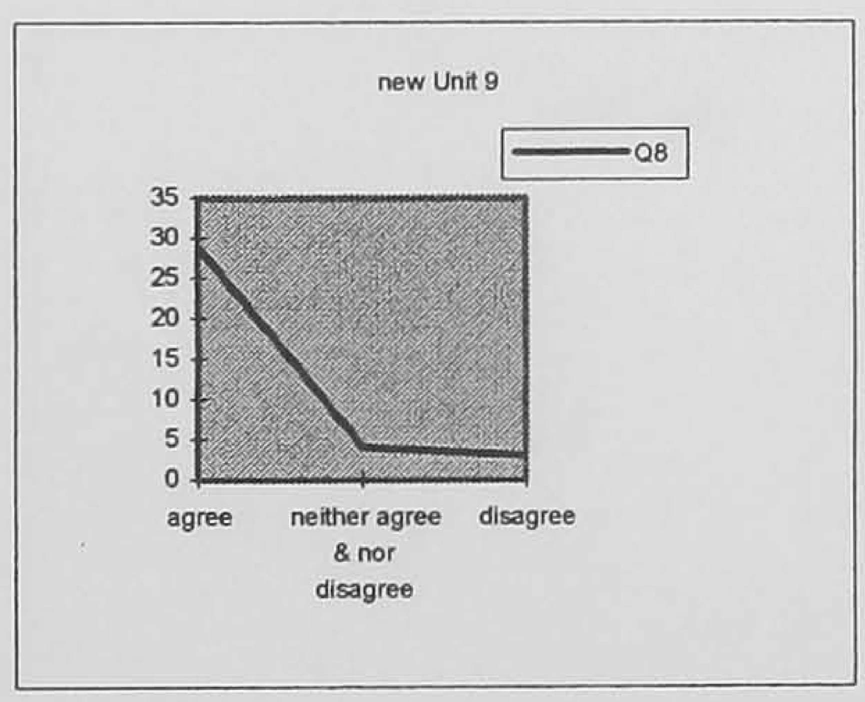
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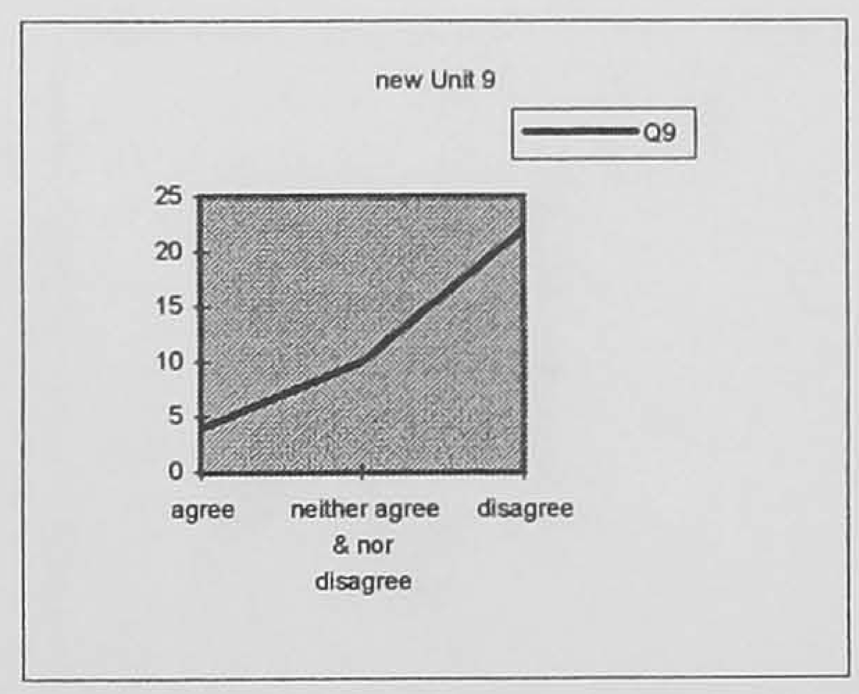
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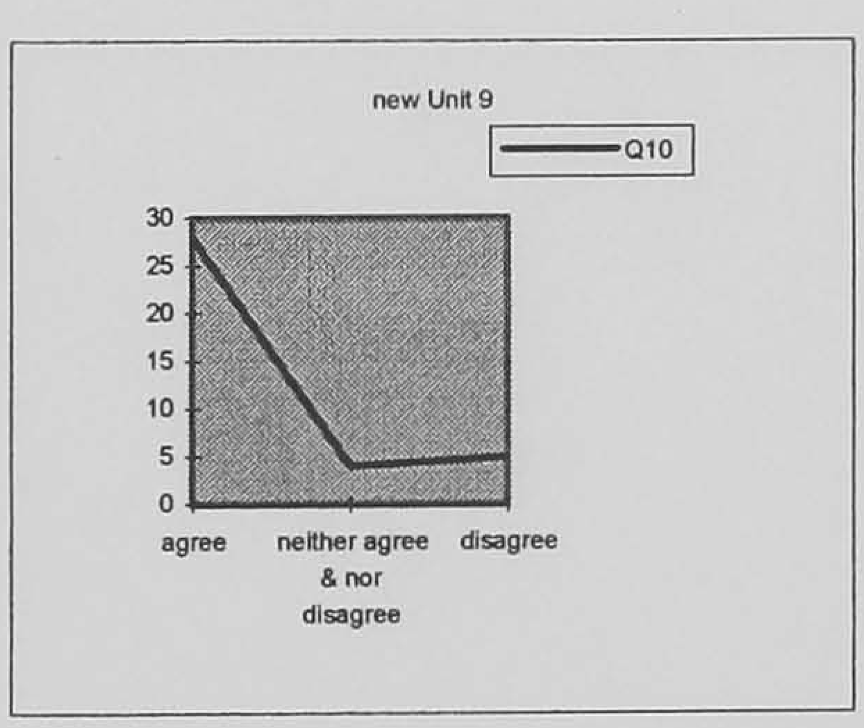
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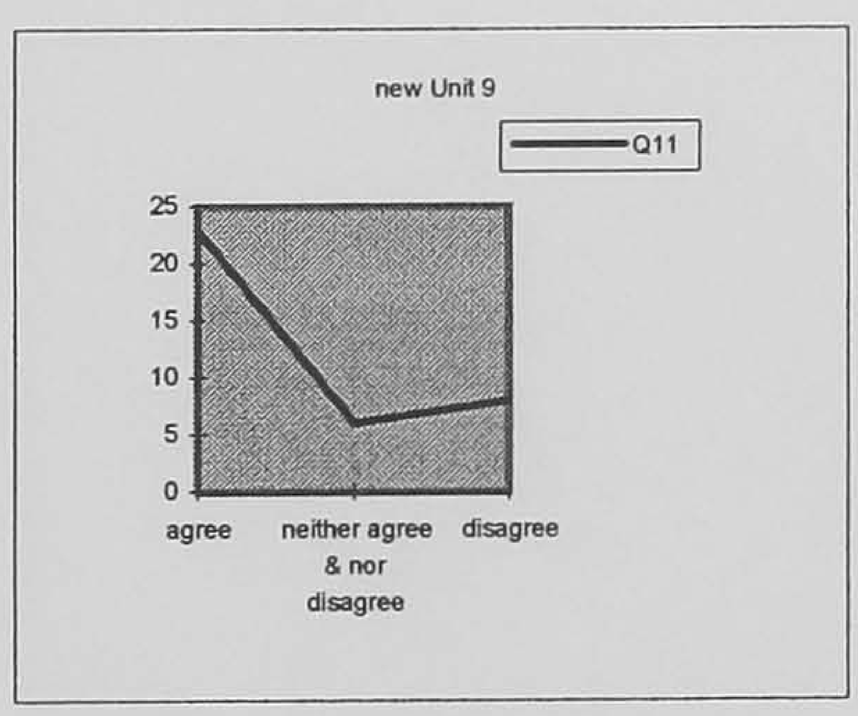
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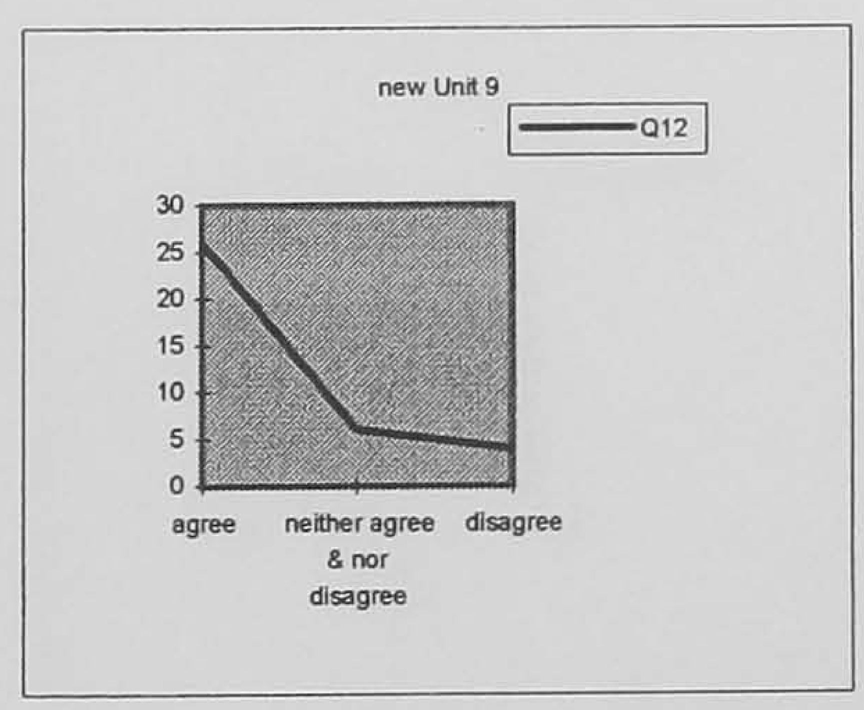
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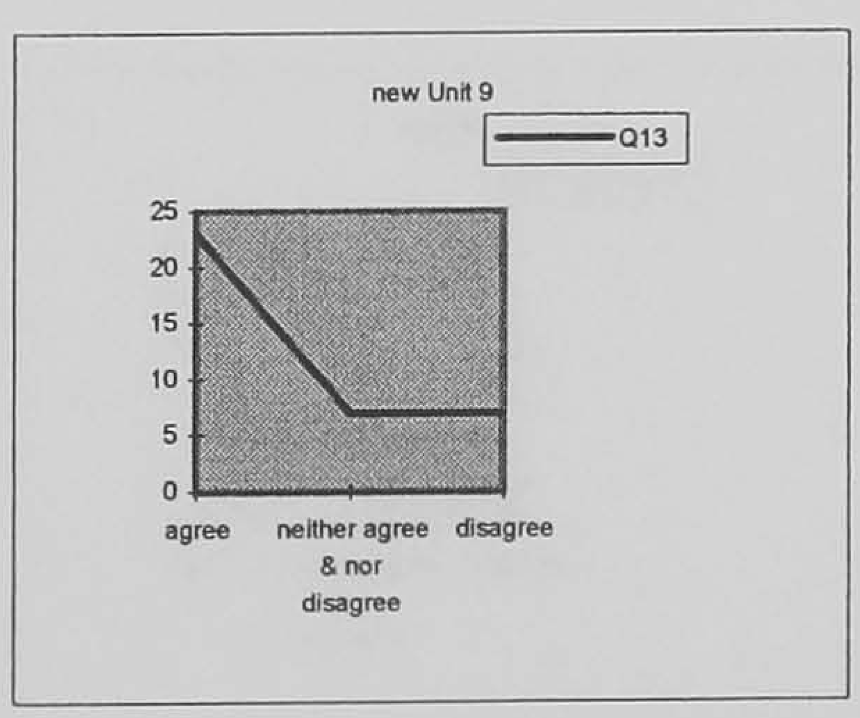
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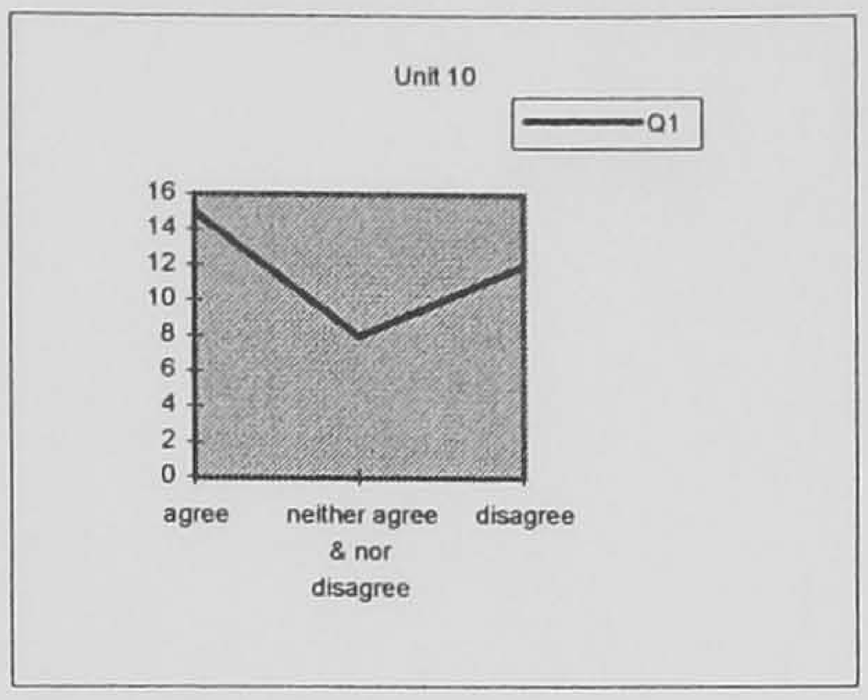
Unit 10



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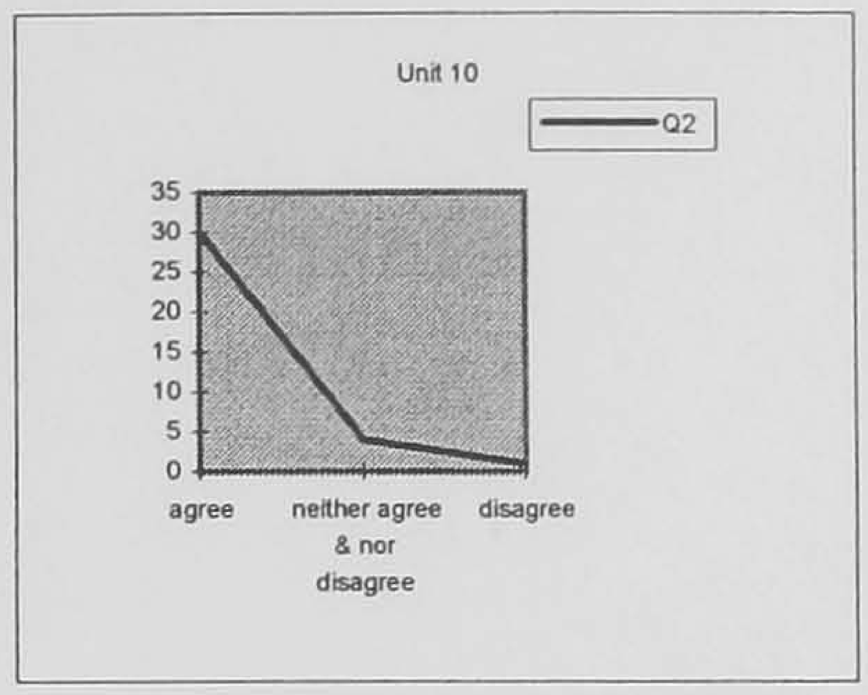

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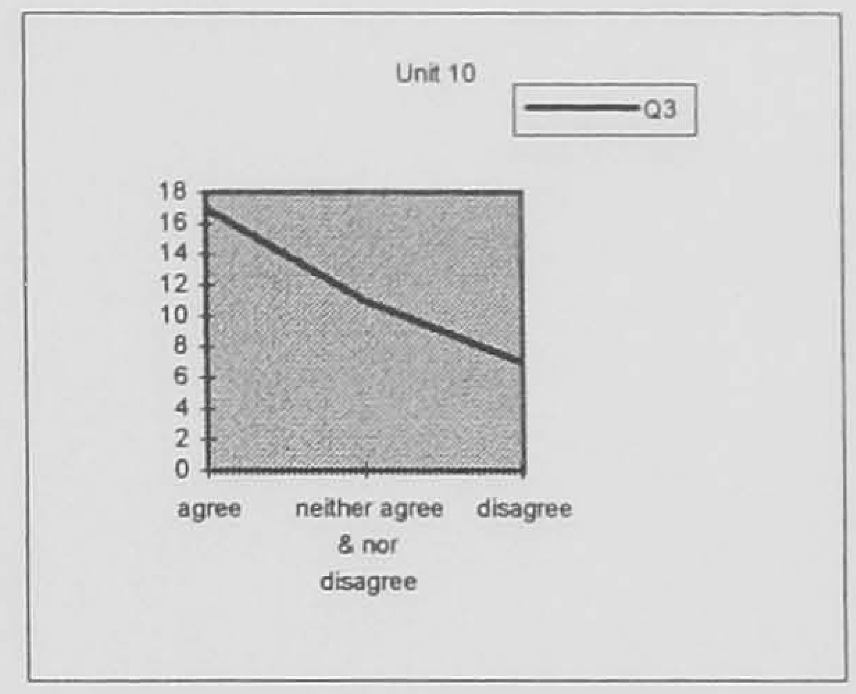

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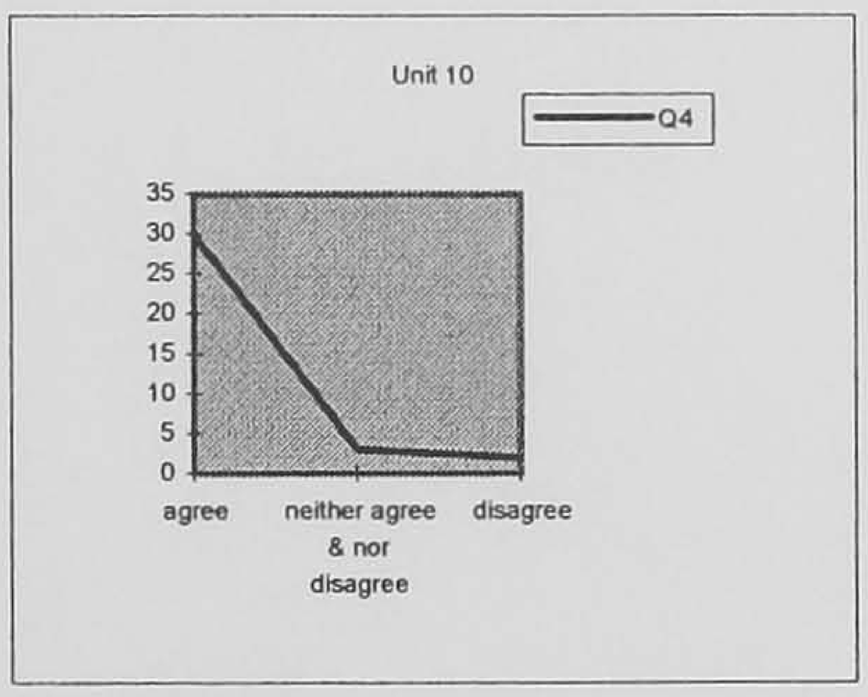

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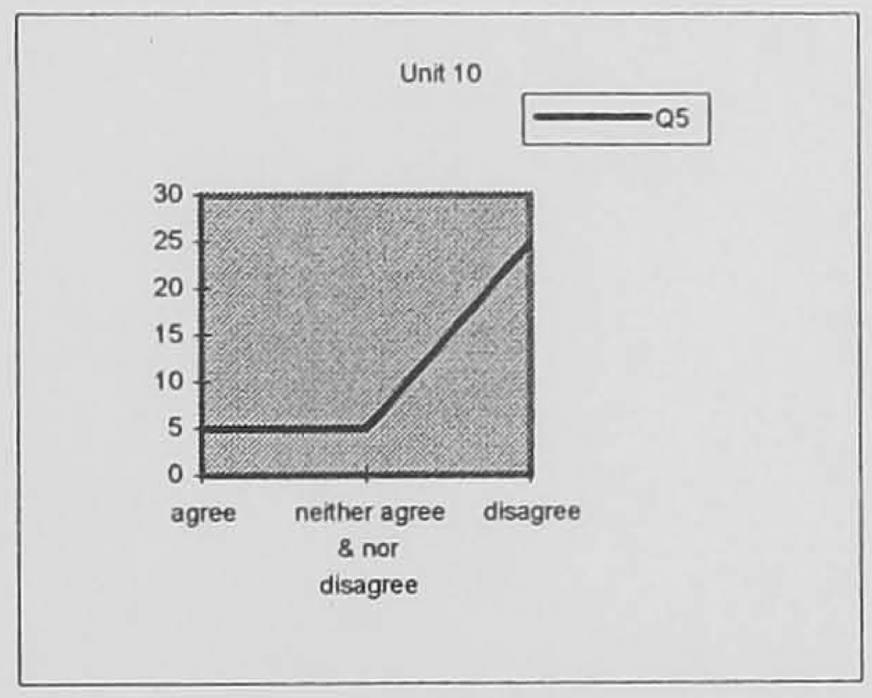

Unit 10
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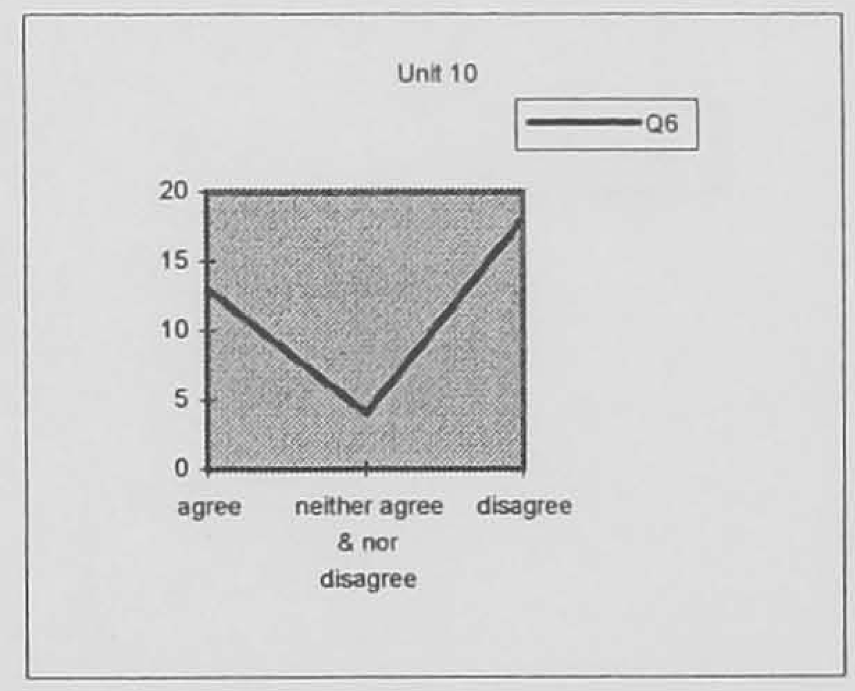

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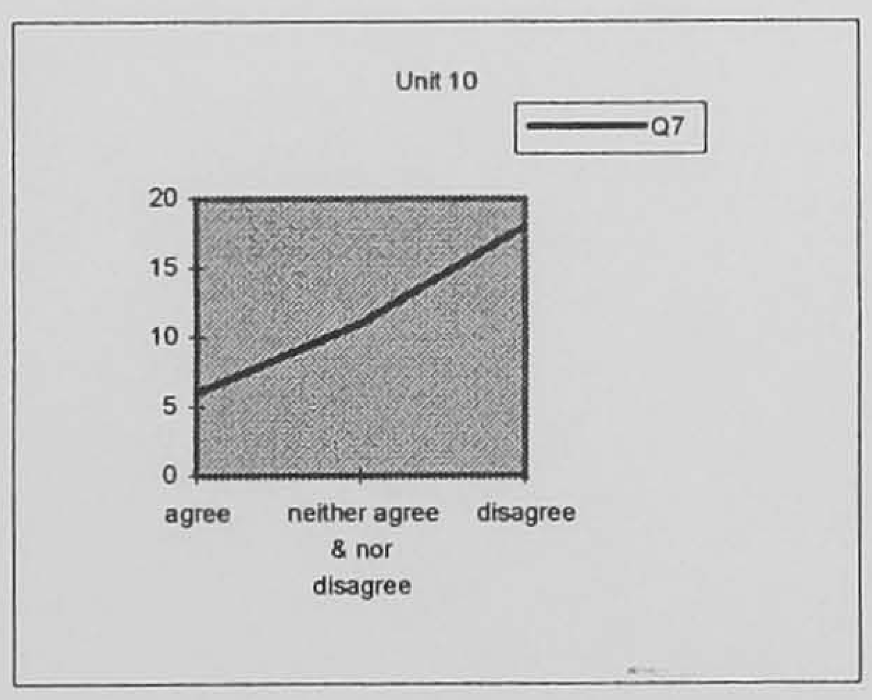

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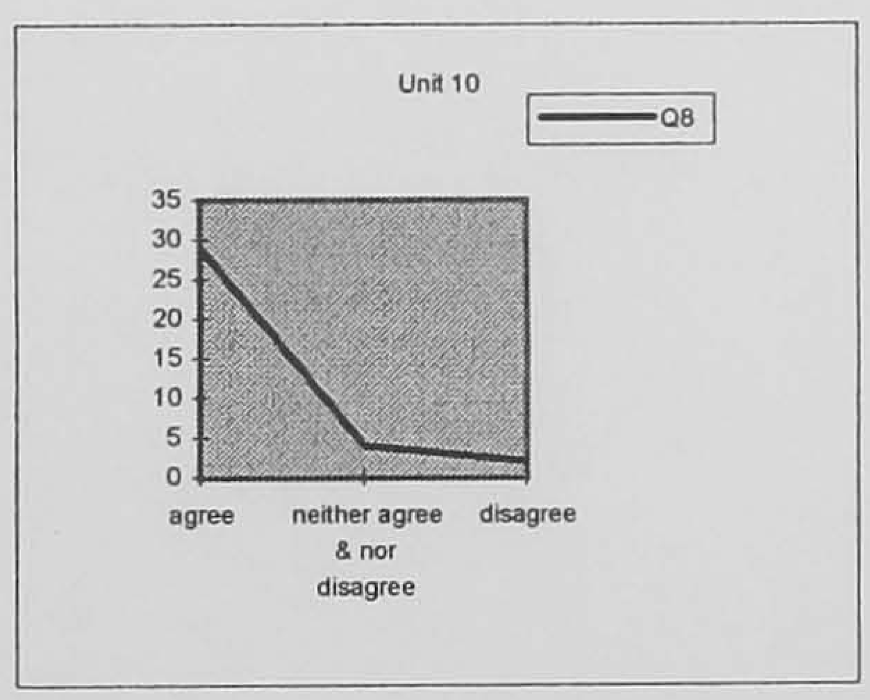

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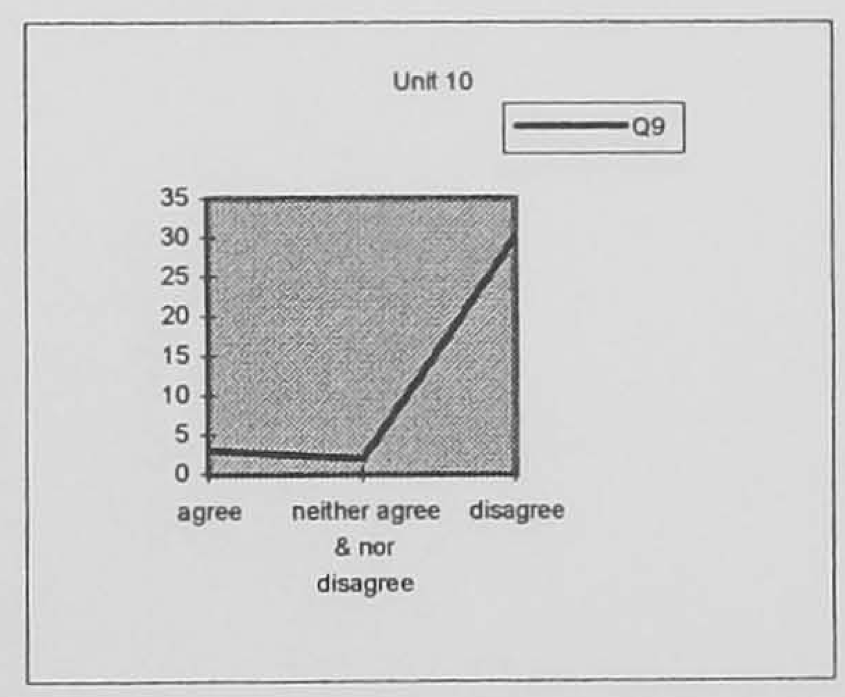

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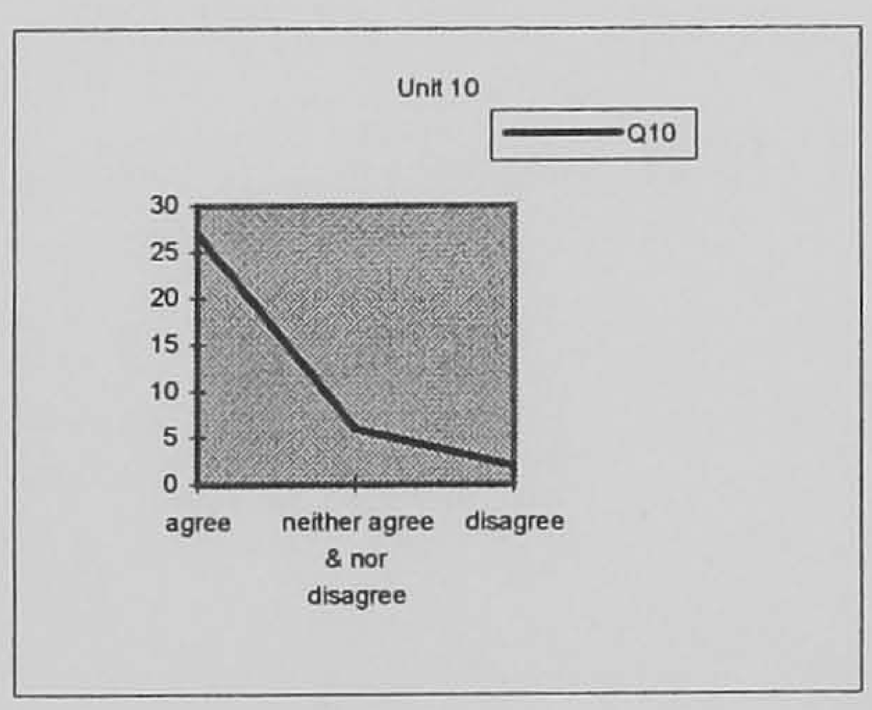

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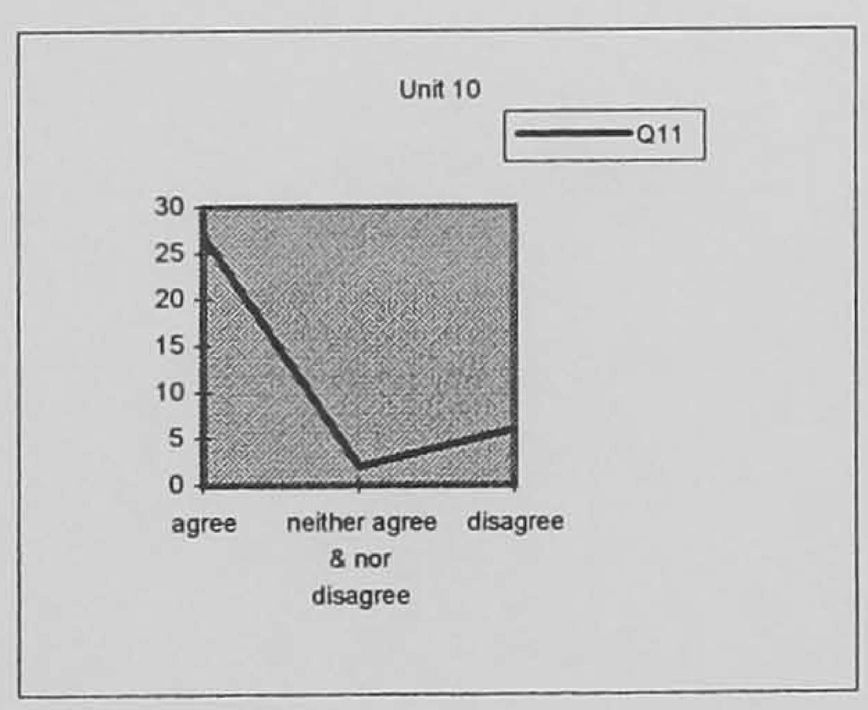

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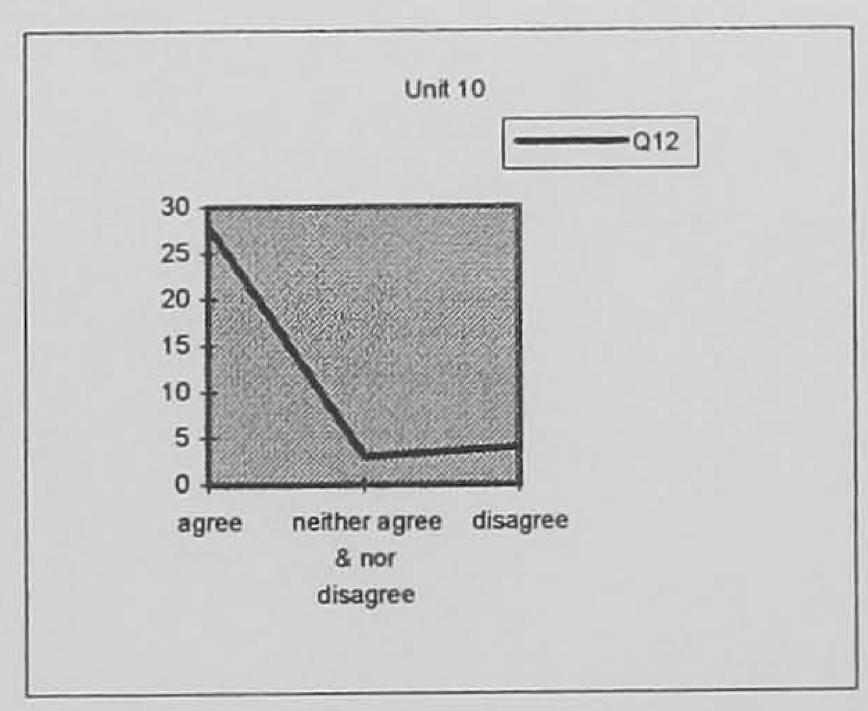

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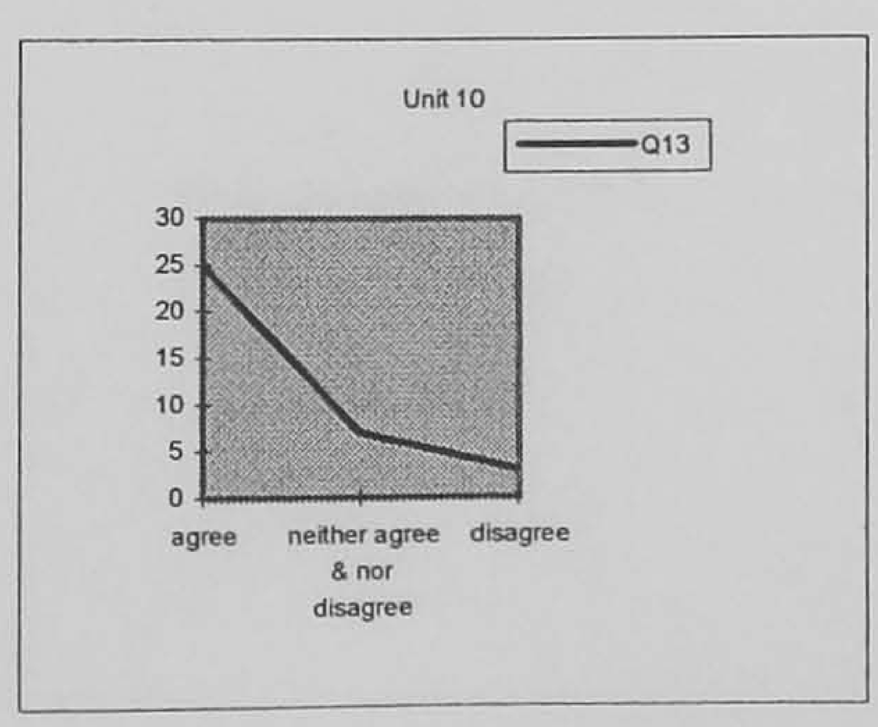

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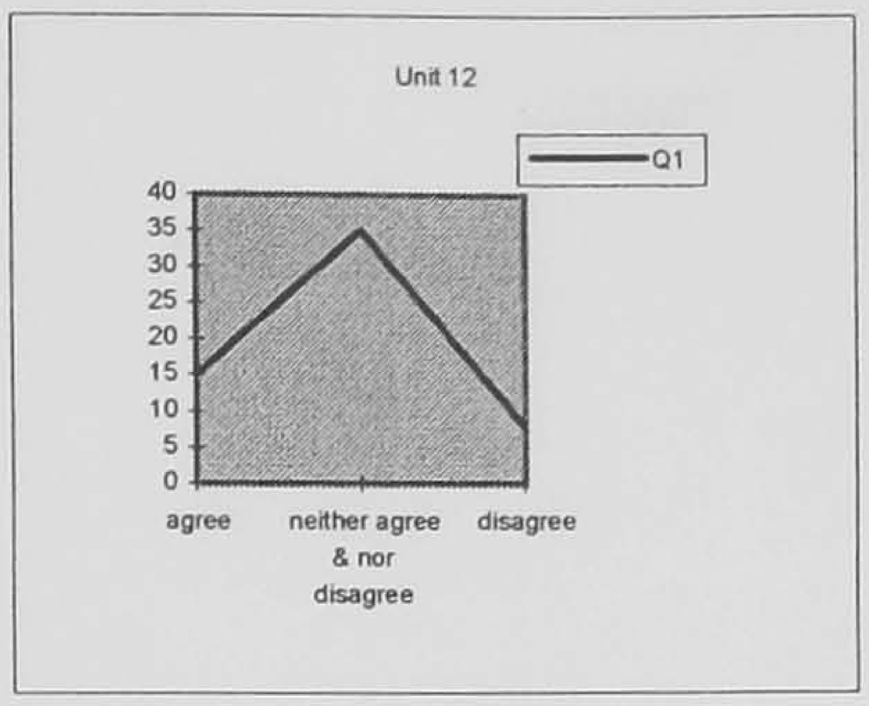
Unit 12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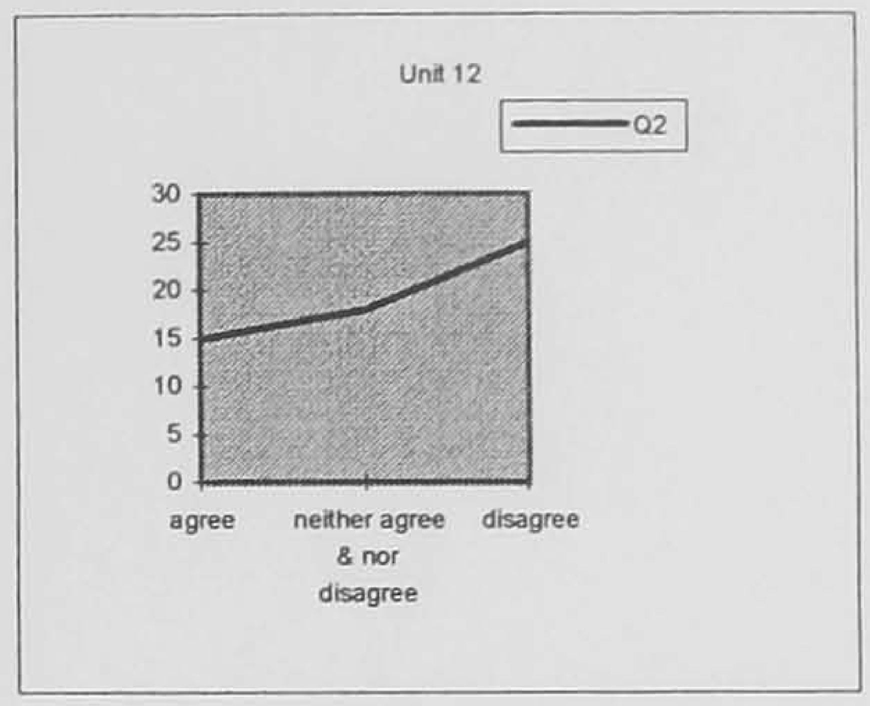
neither agree & nor disagree
disagree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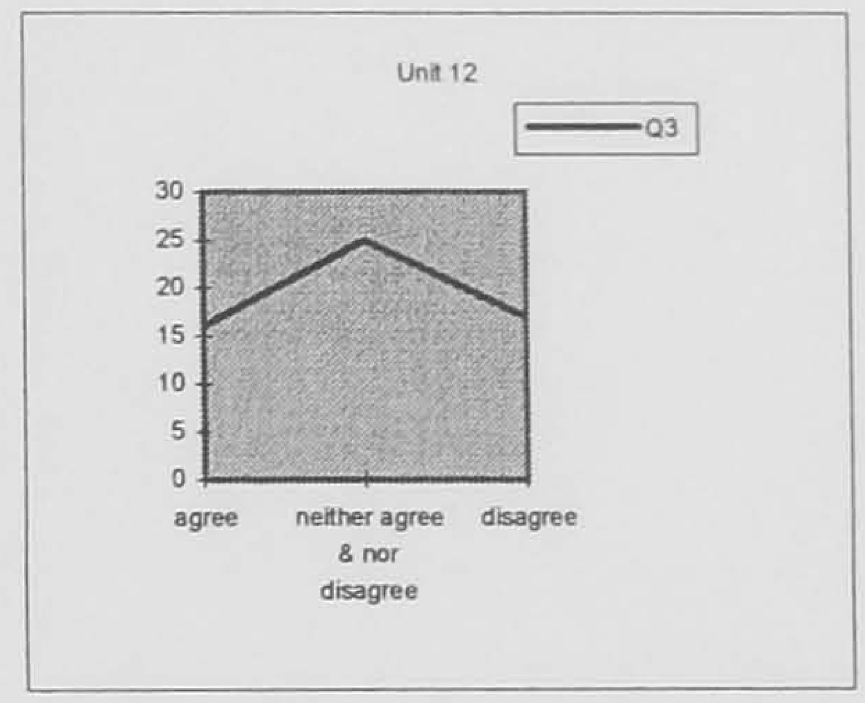
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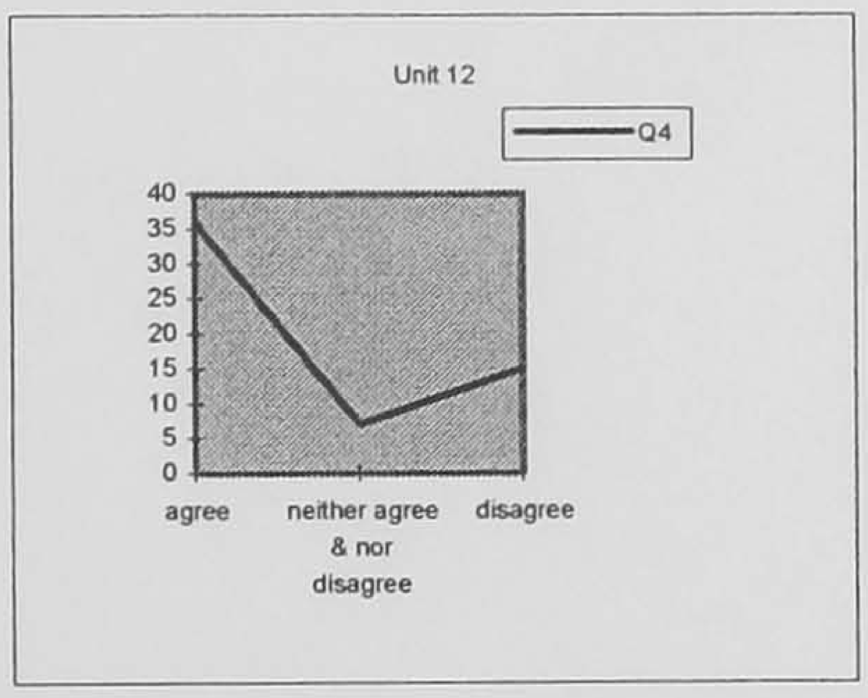
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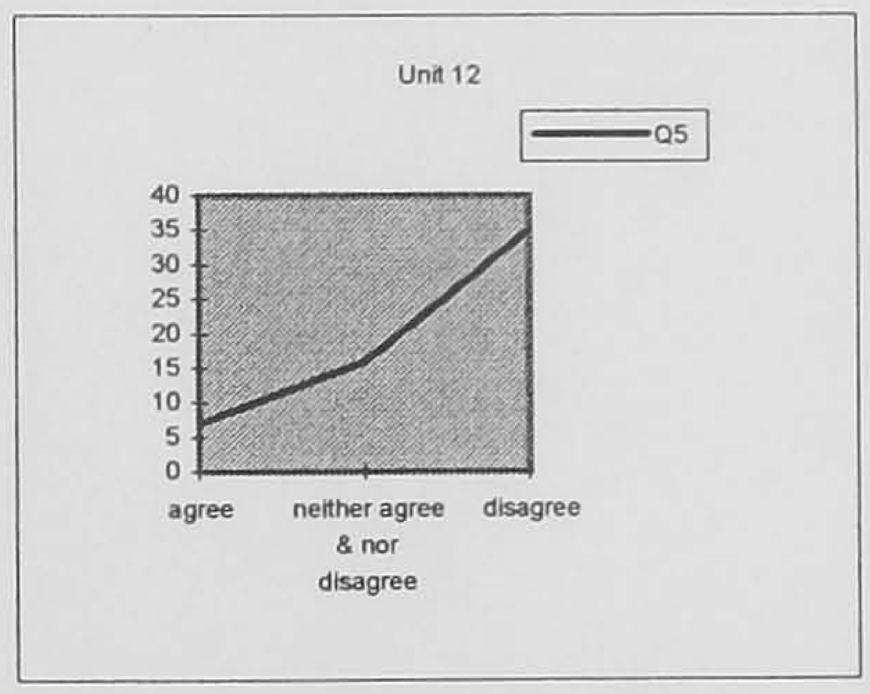
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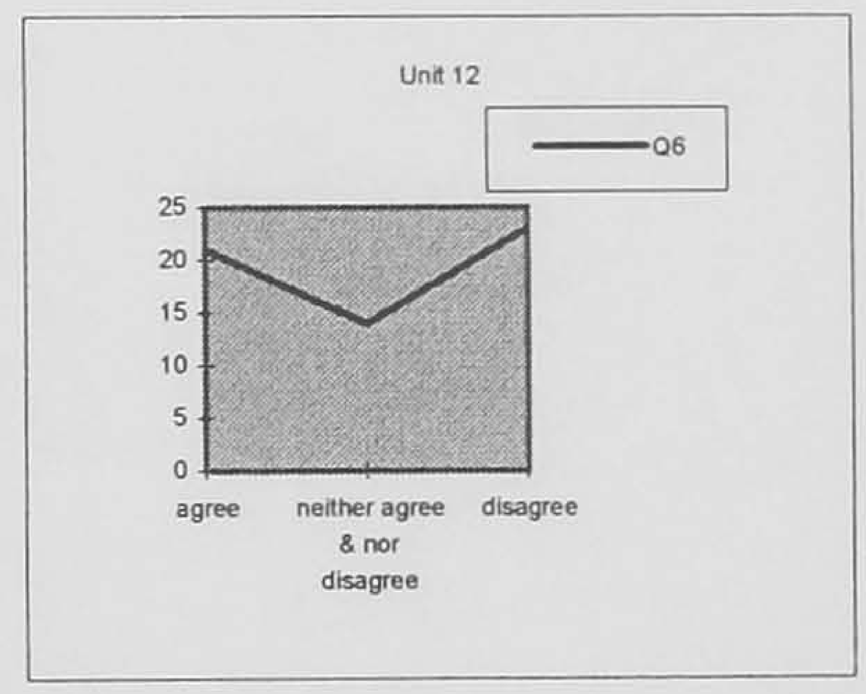
disagree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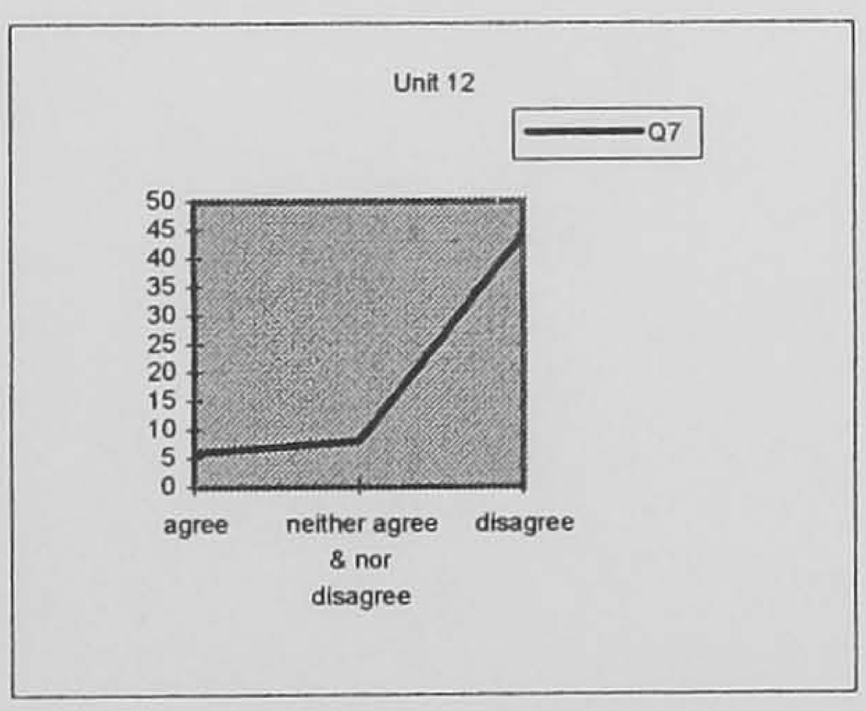
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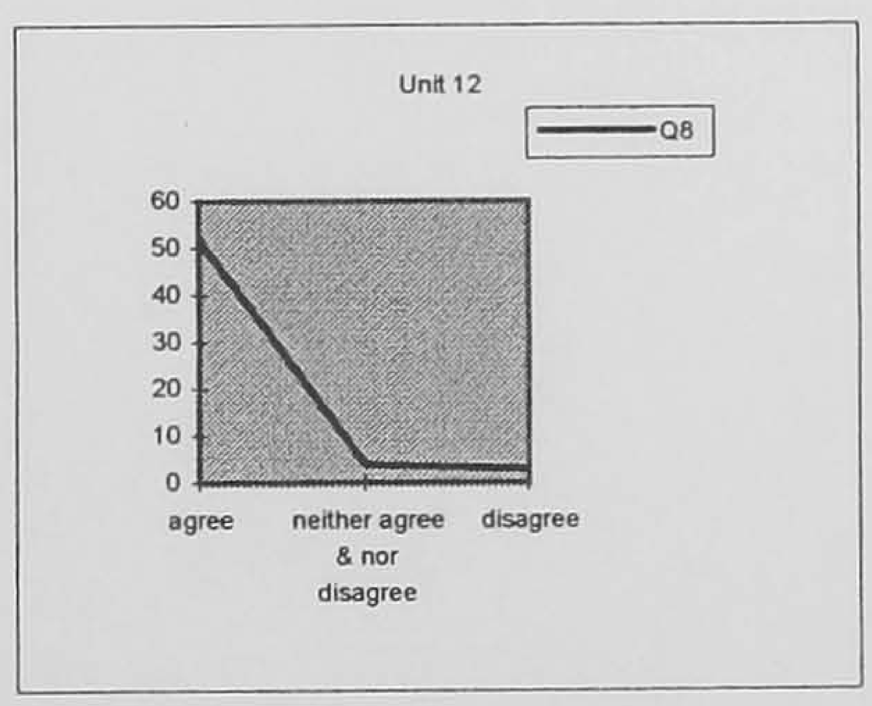
disagree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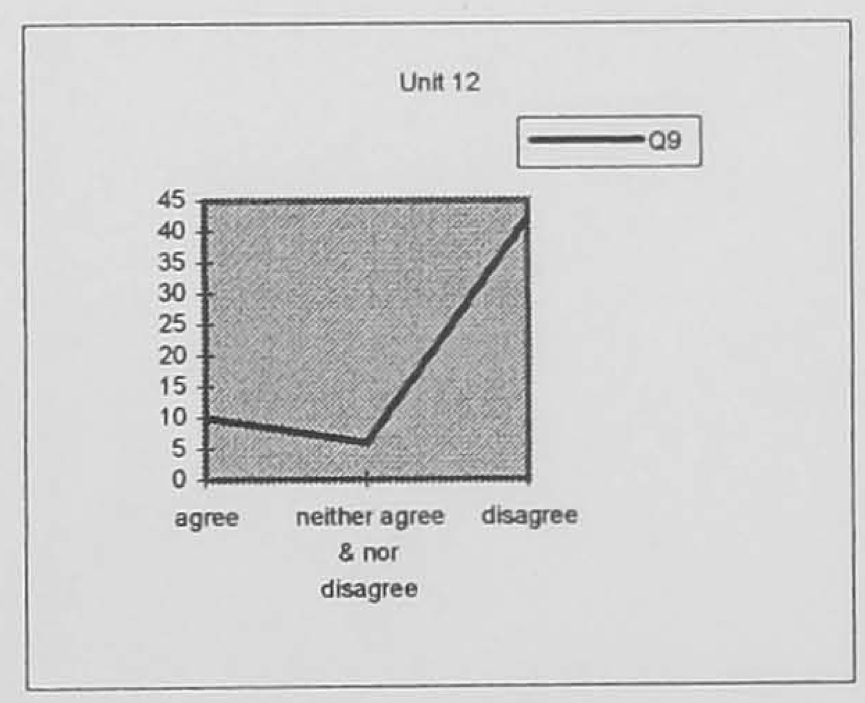
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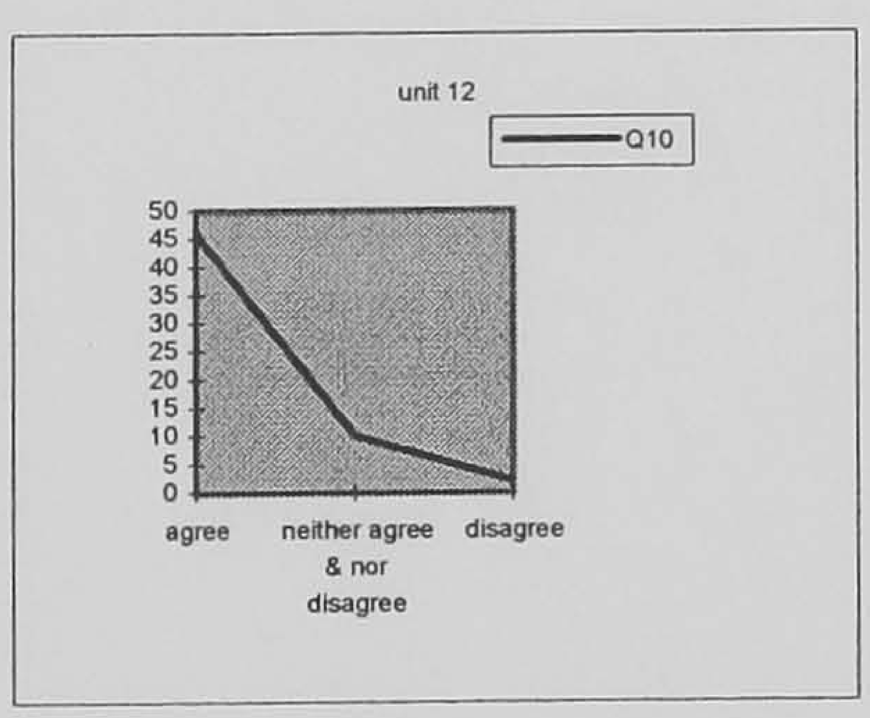
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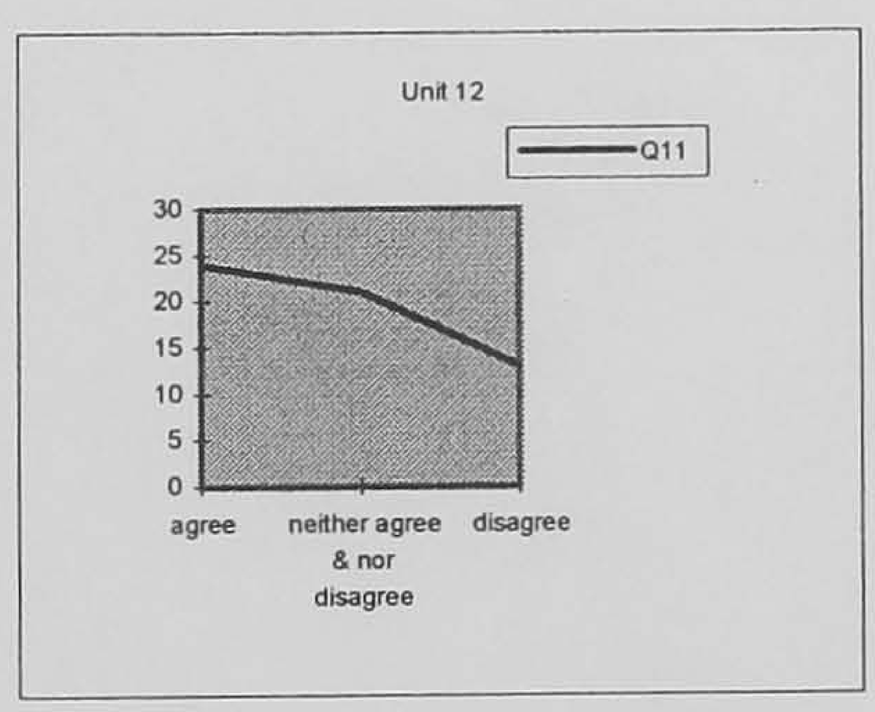
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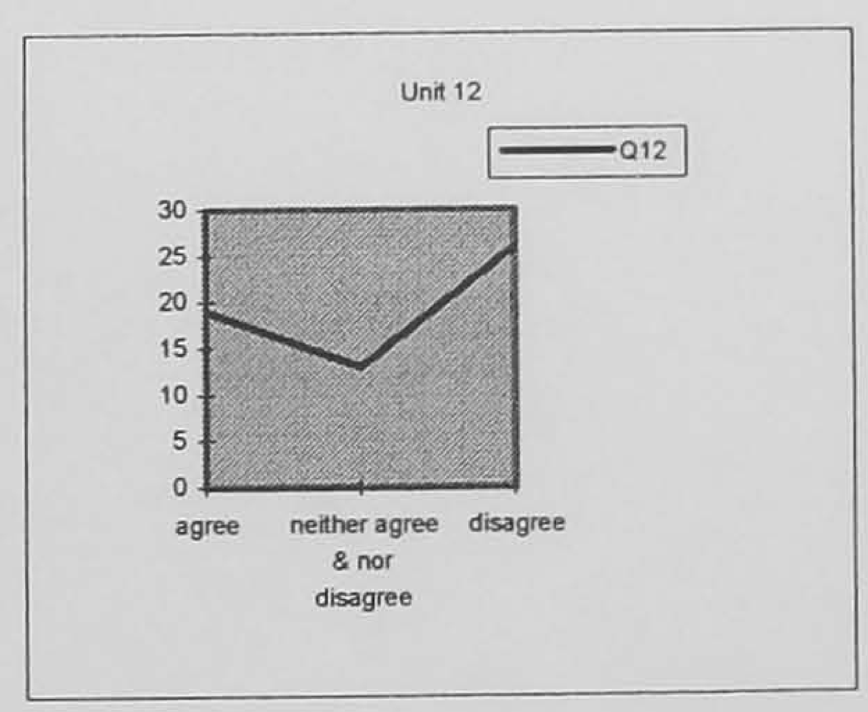
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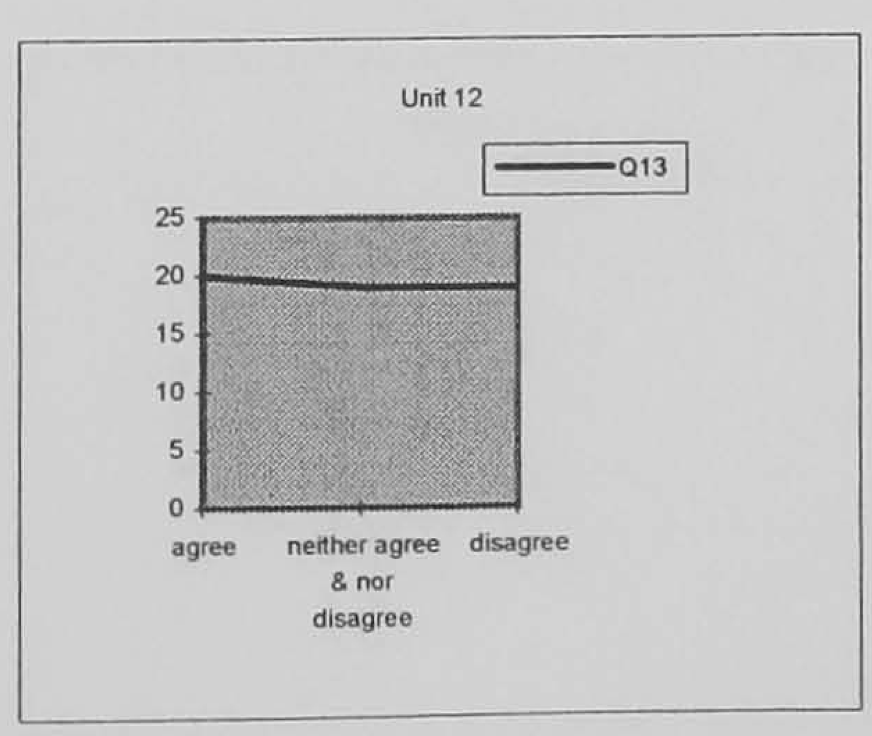
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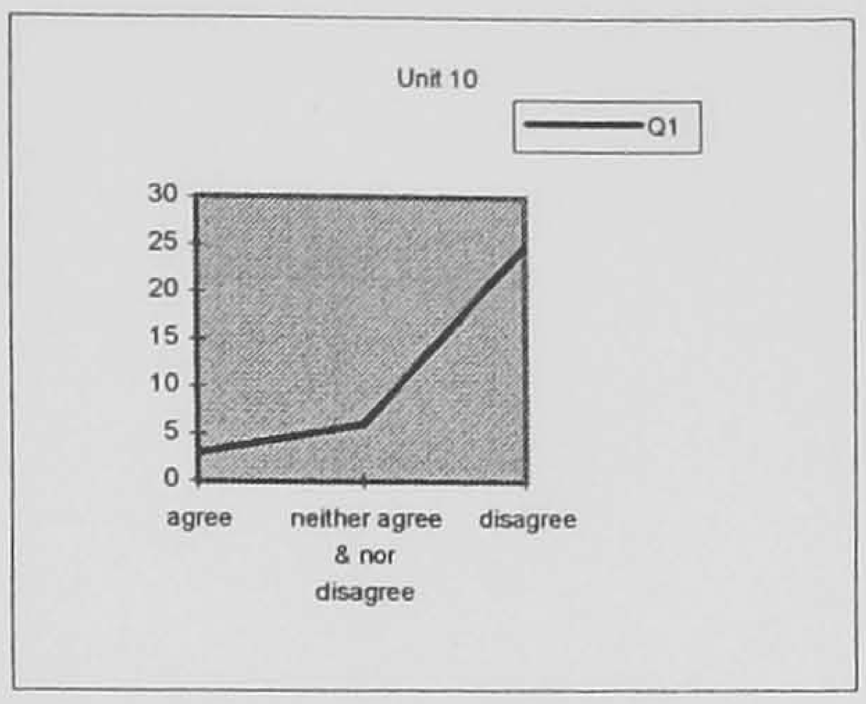
Unit 13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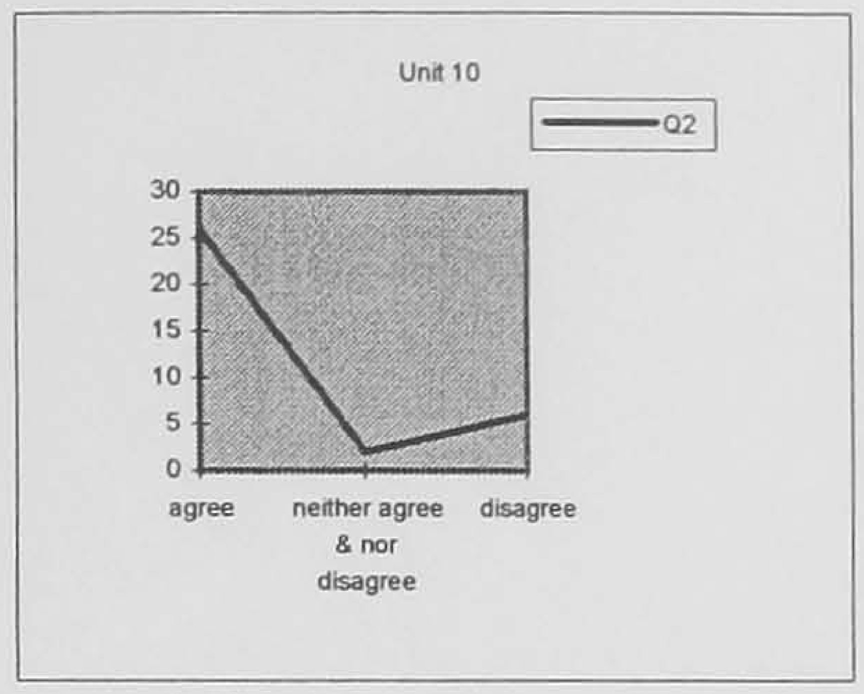
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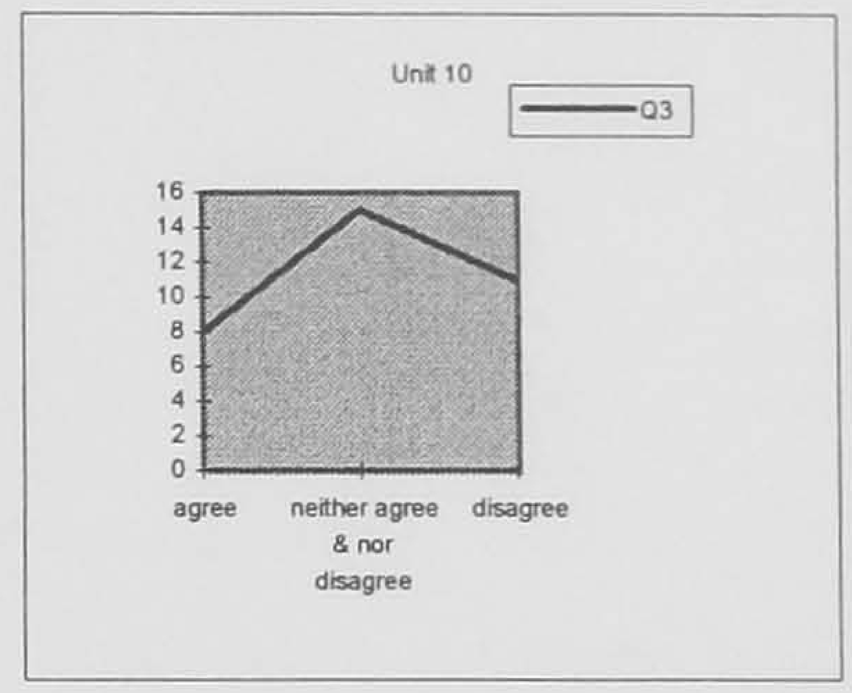
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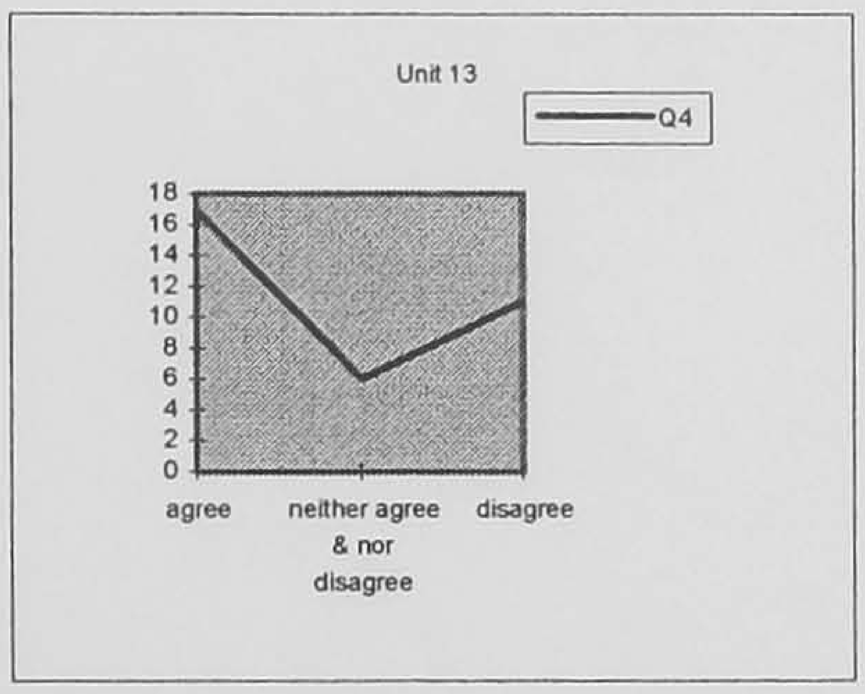
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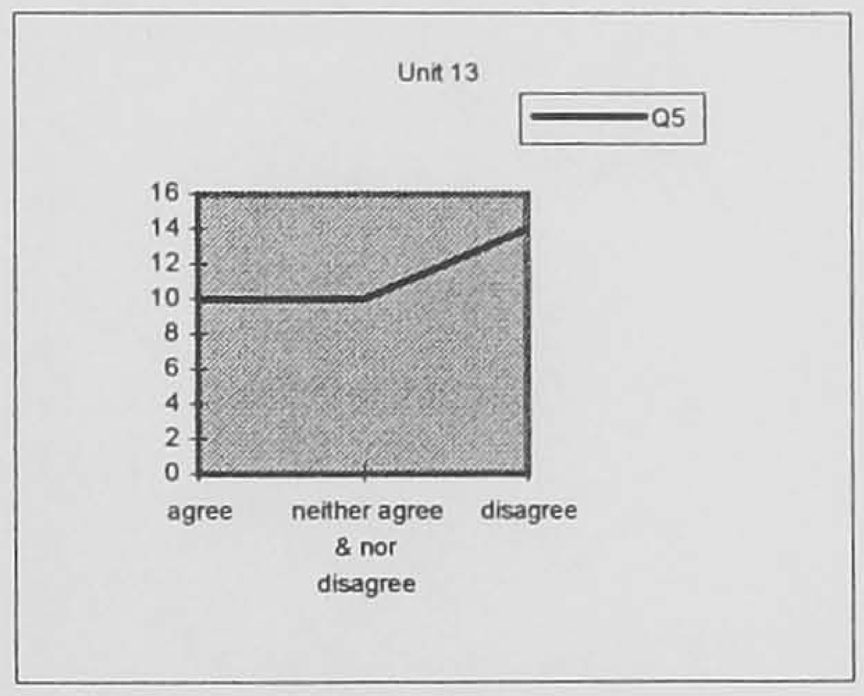
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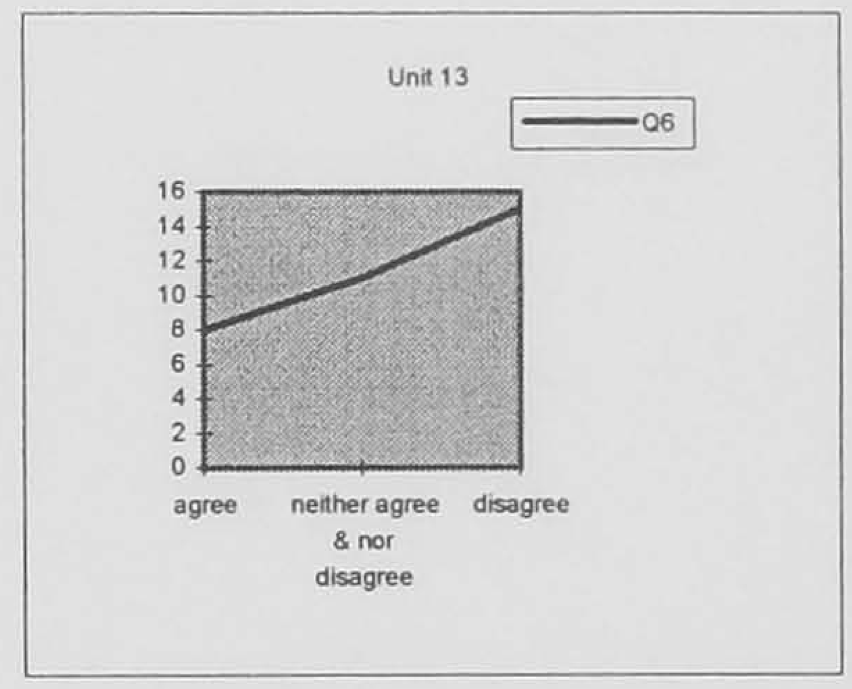
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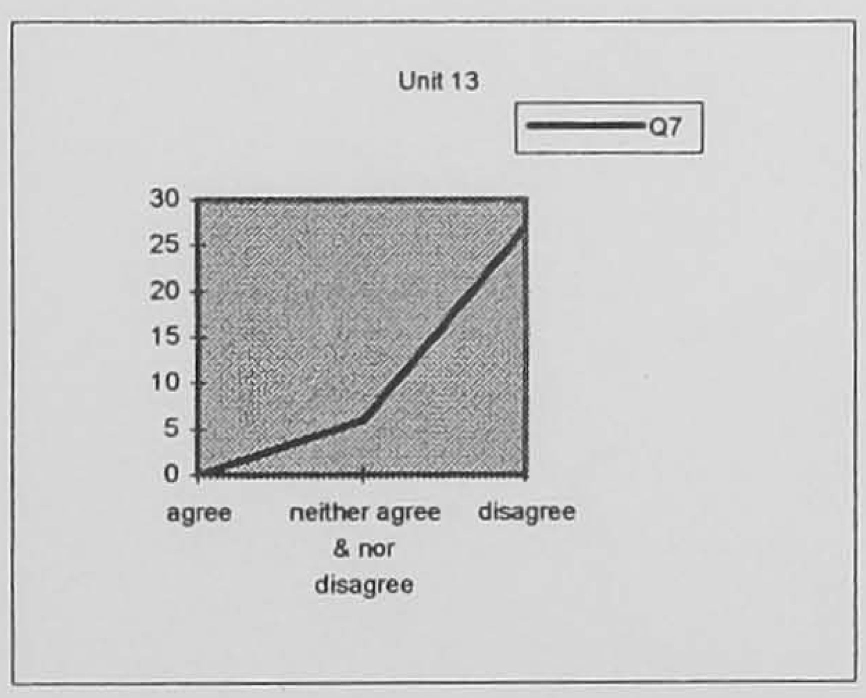
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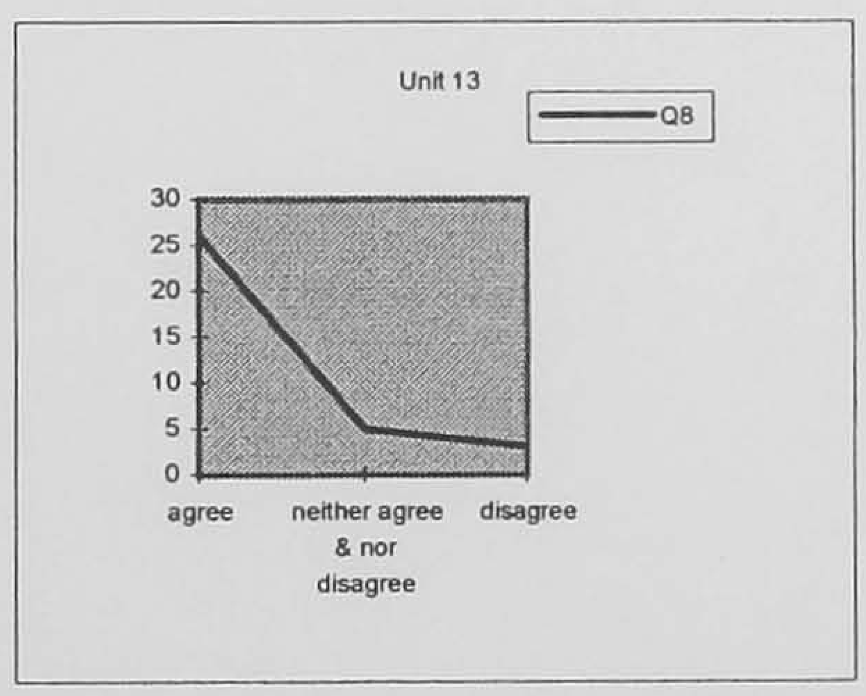
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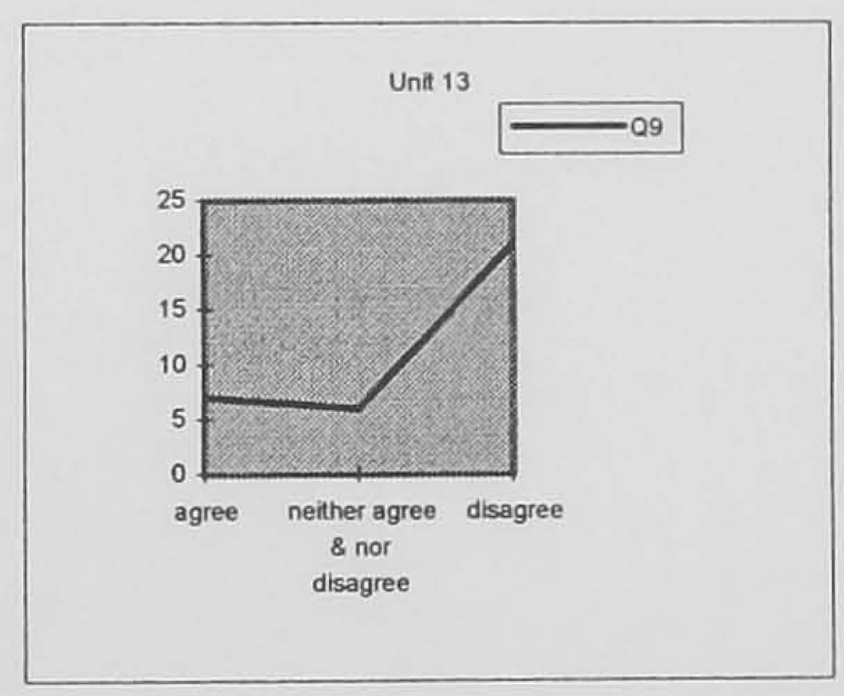
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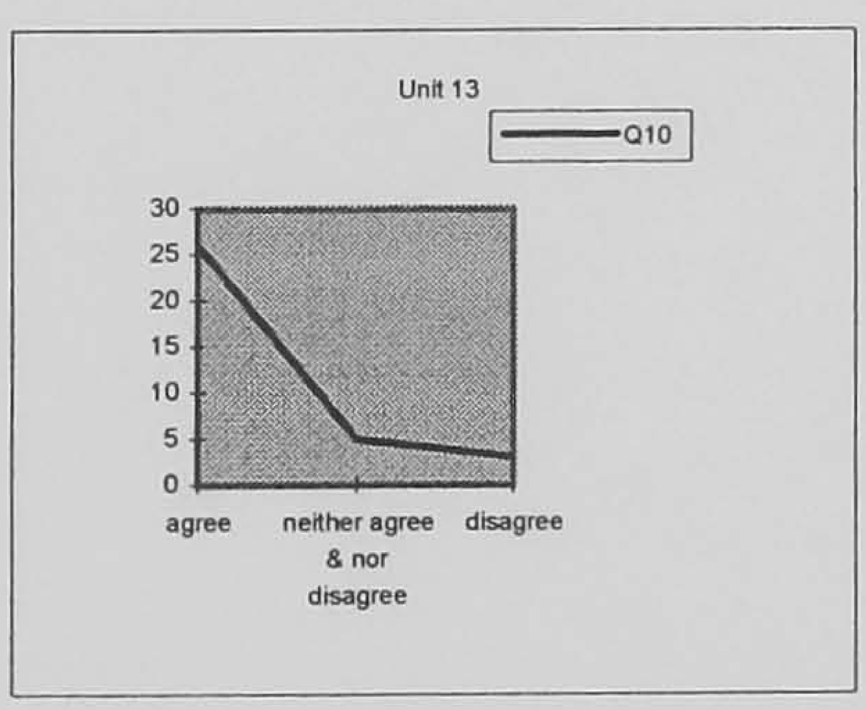
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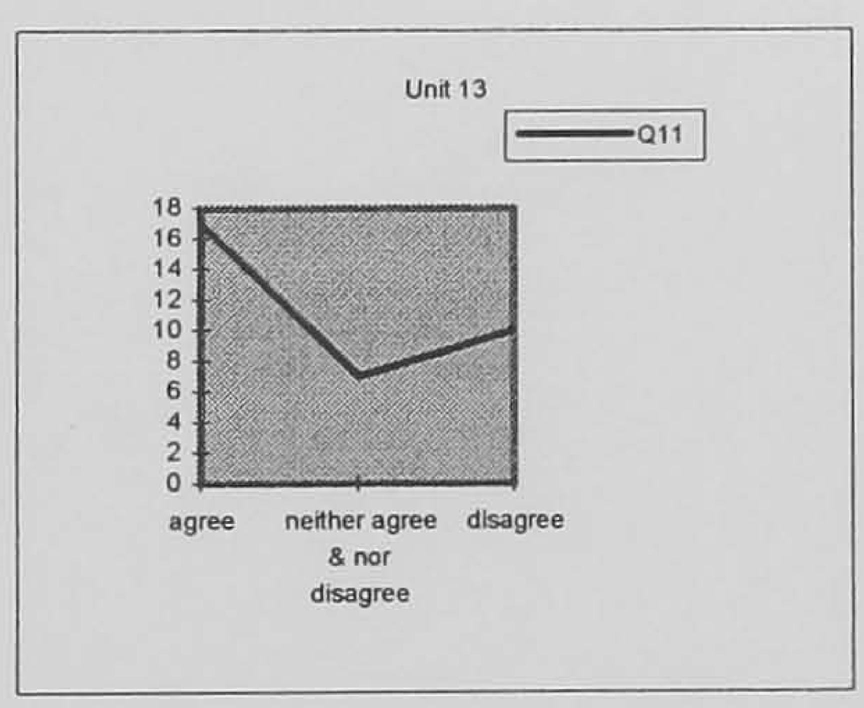
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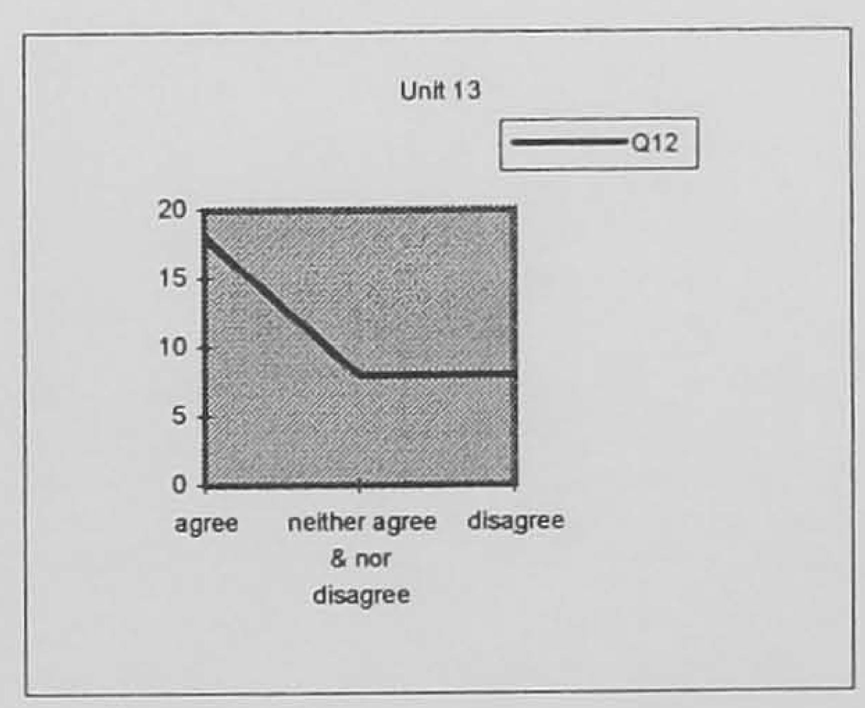
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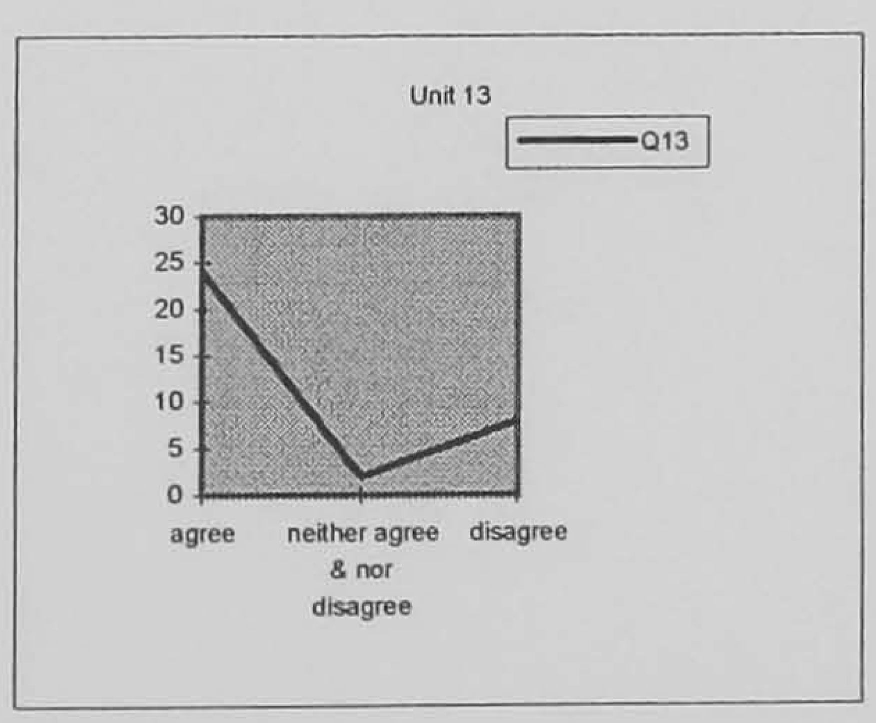
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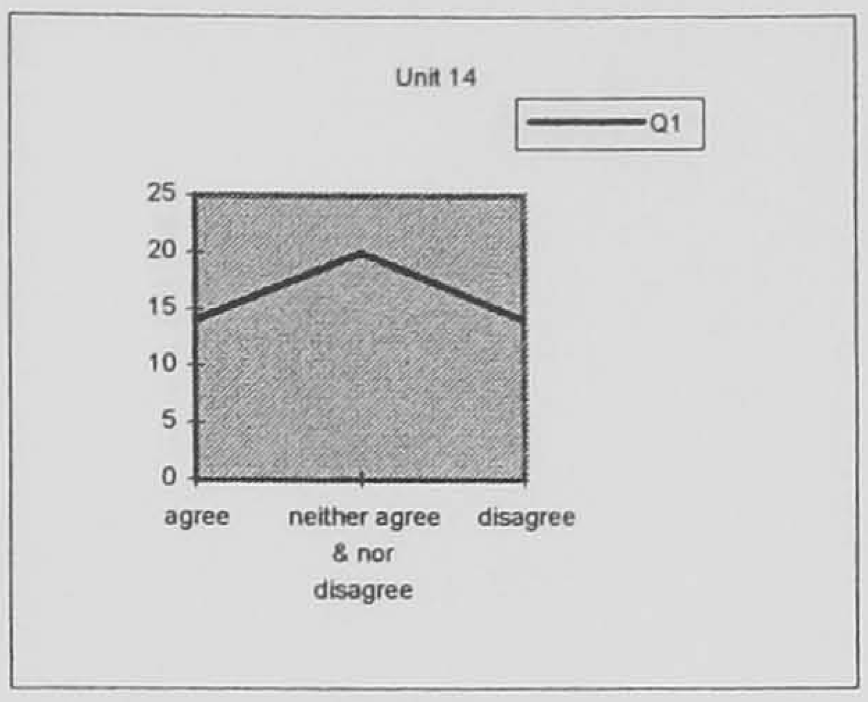
Unit 14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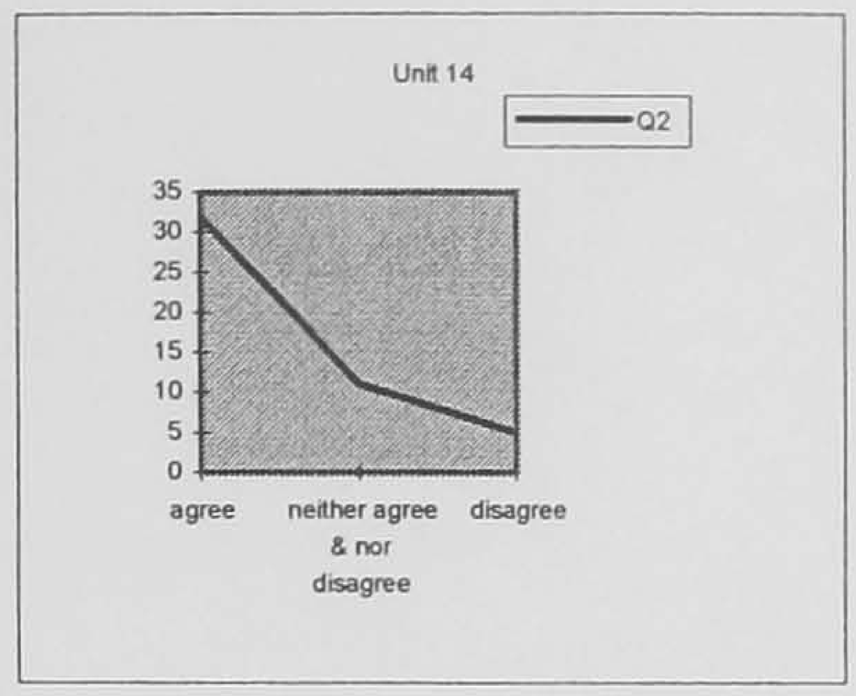
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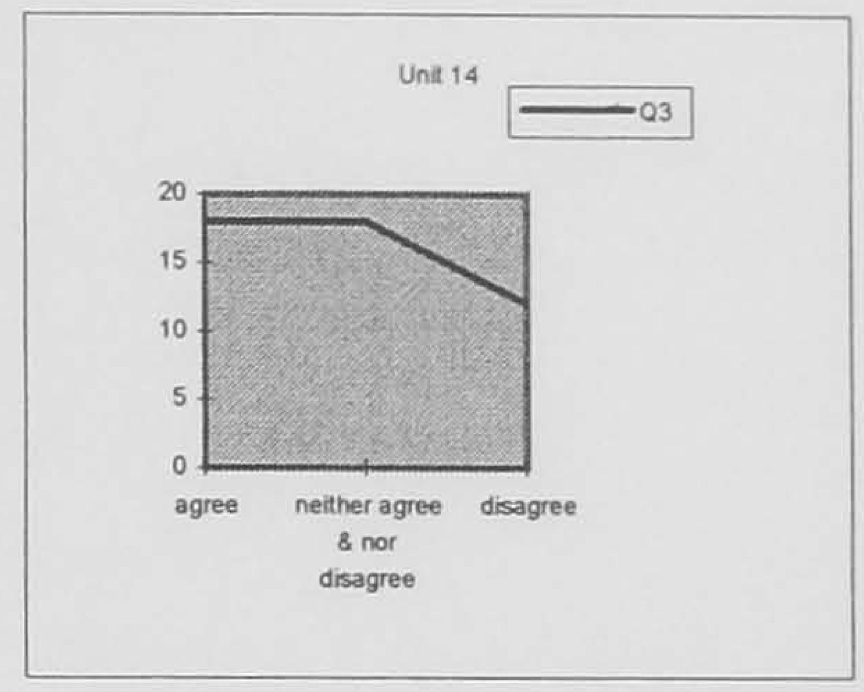
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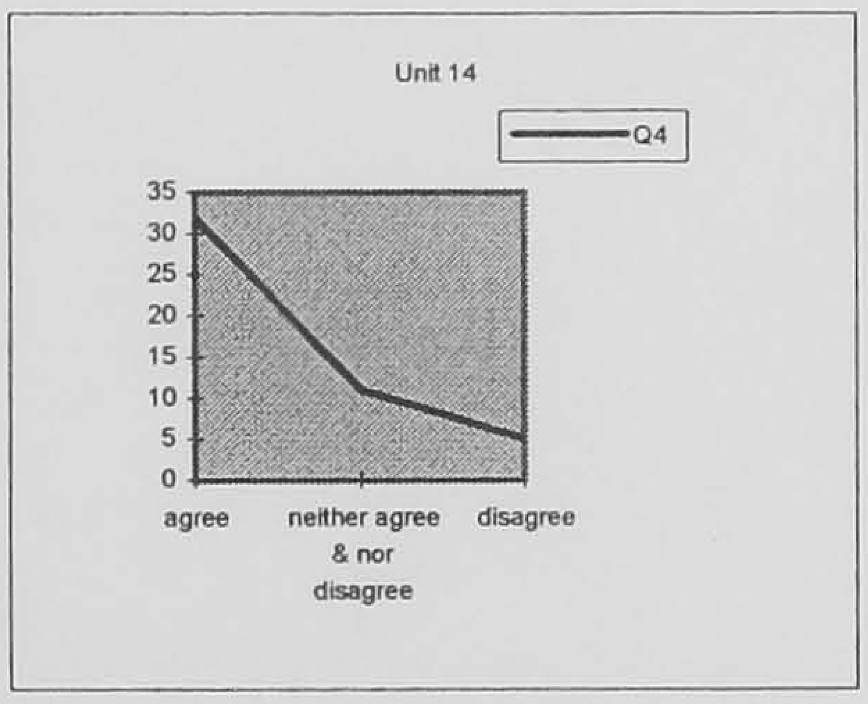
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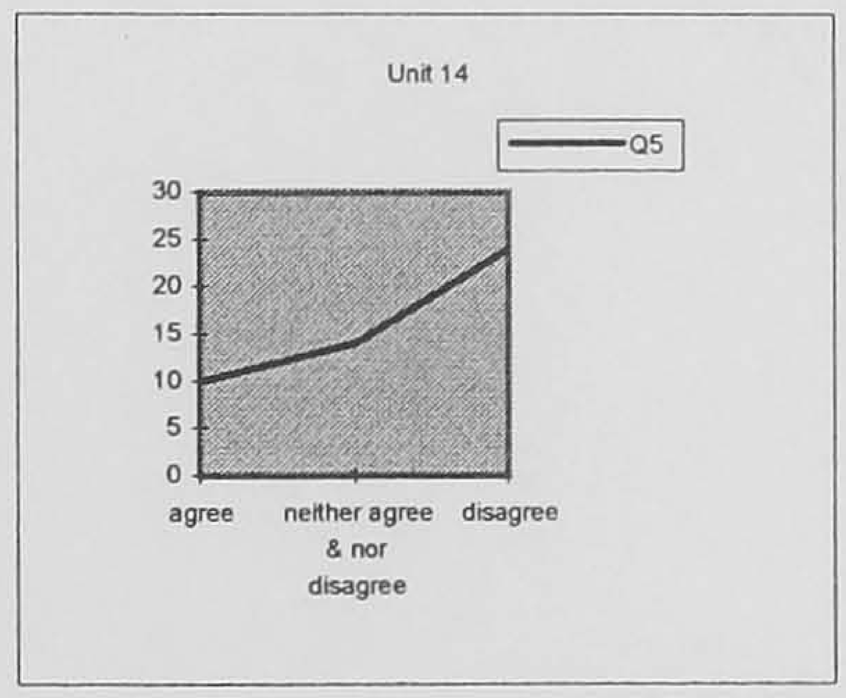
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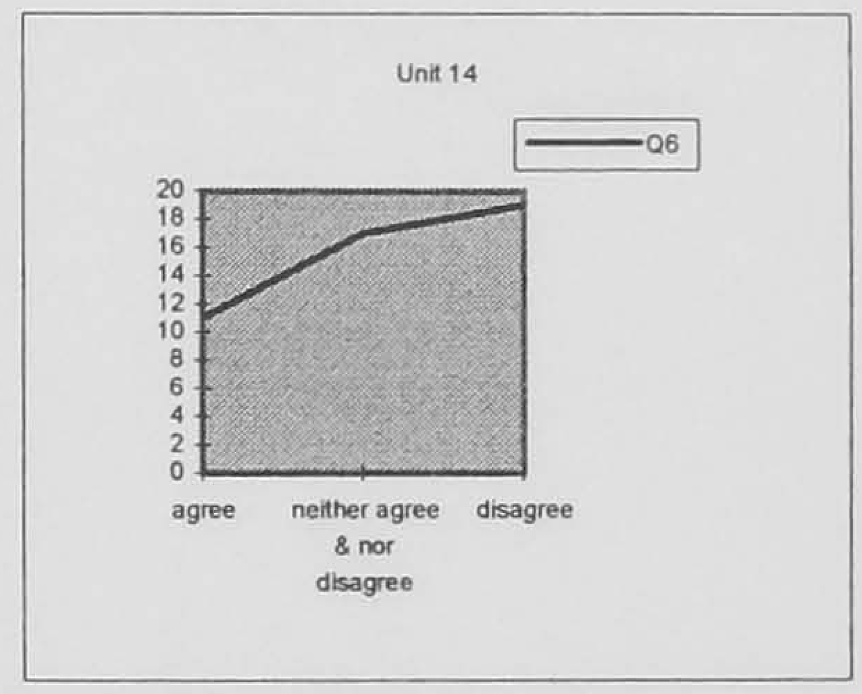
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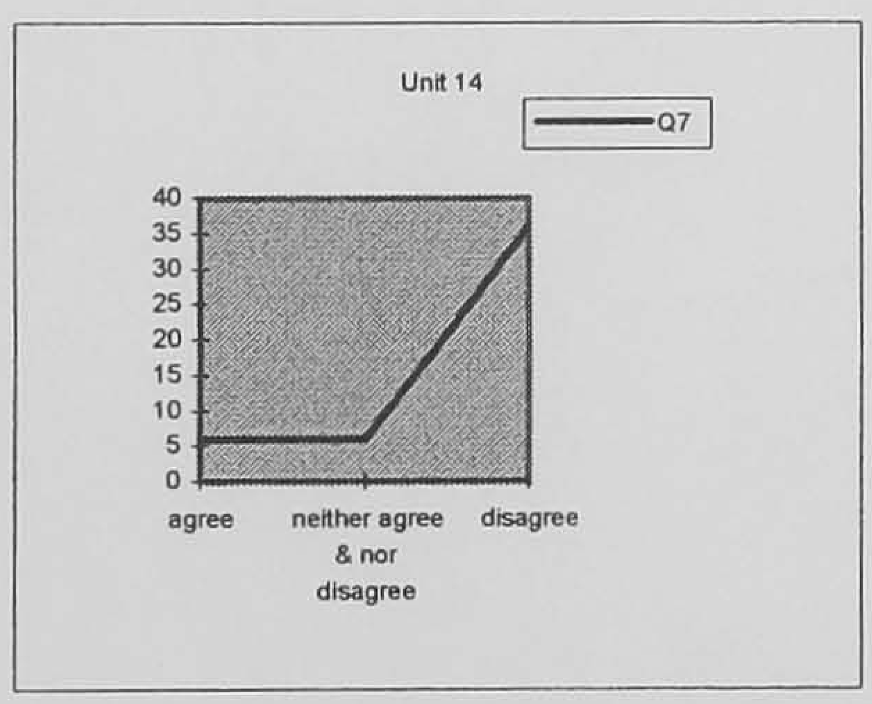
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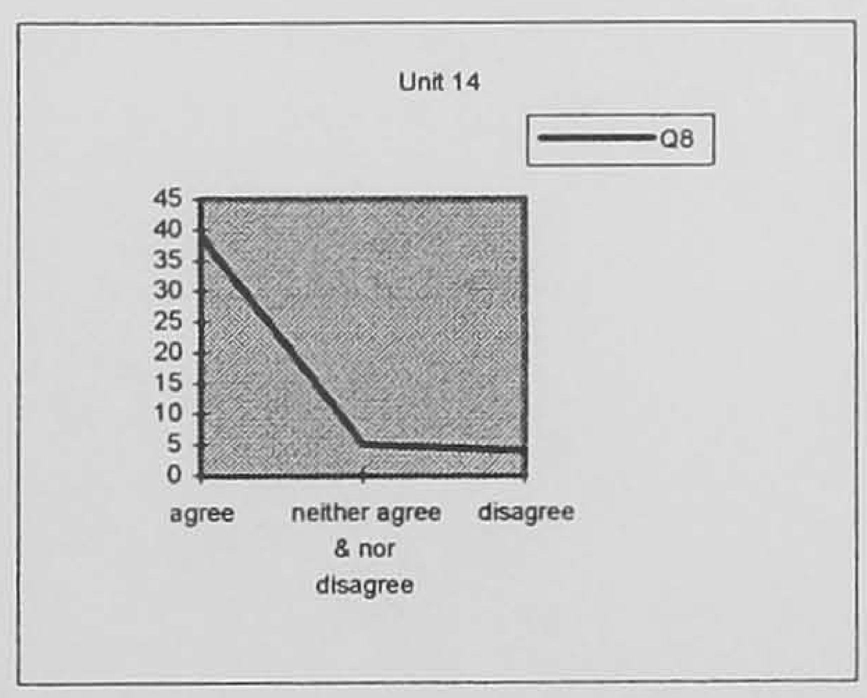
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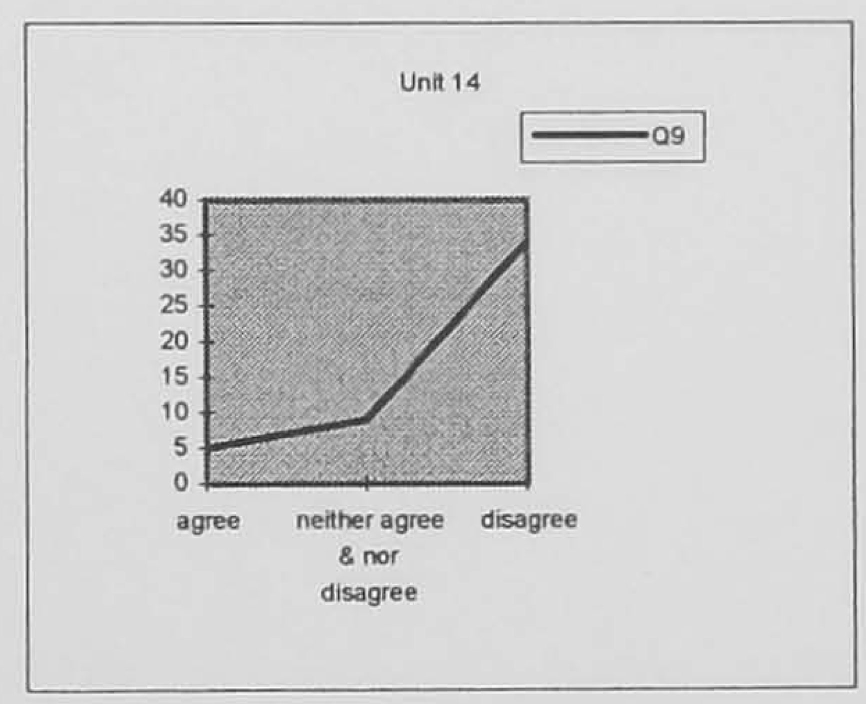
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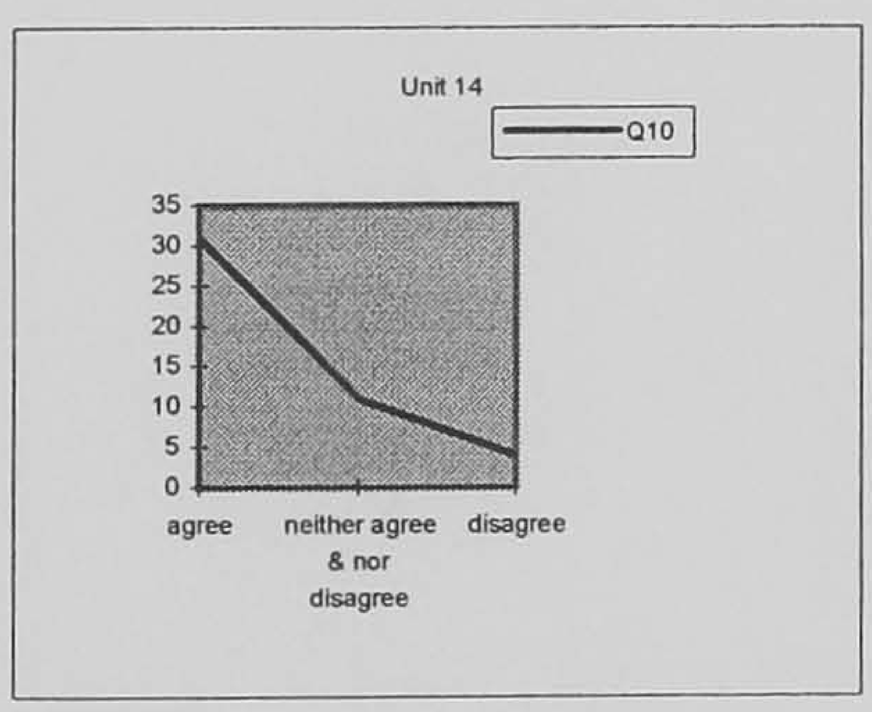
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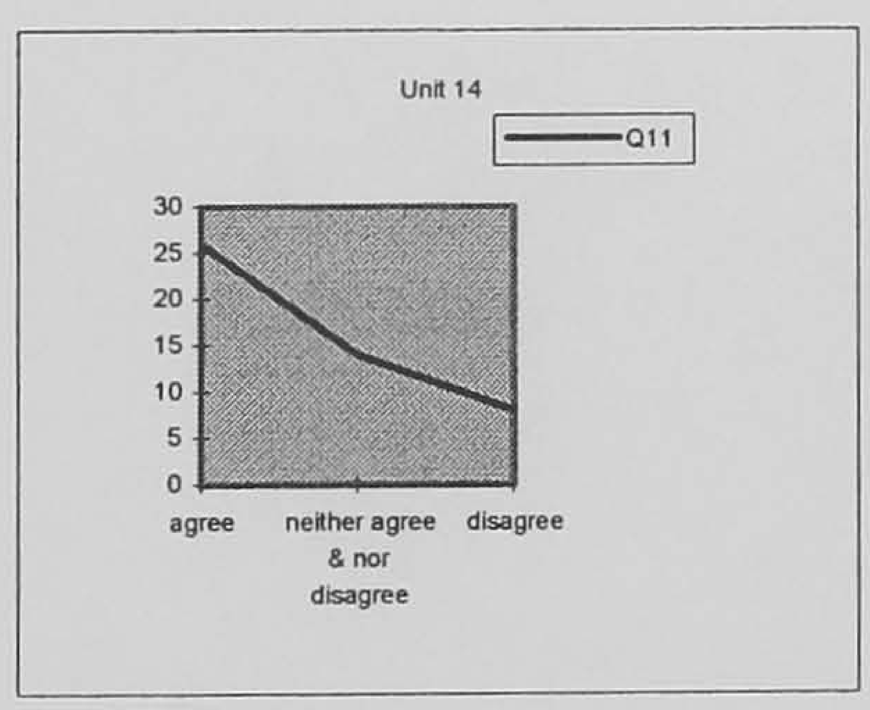
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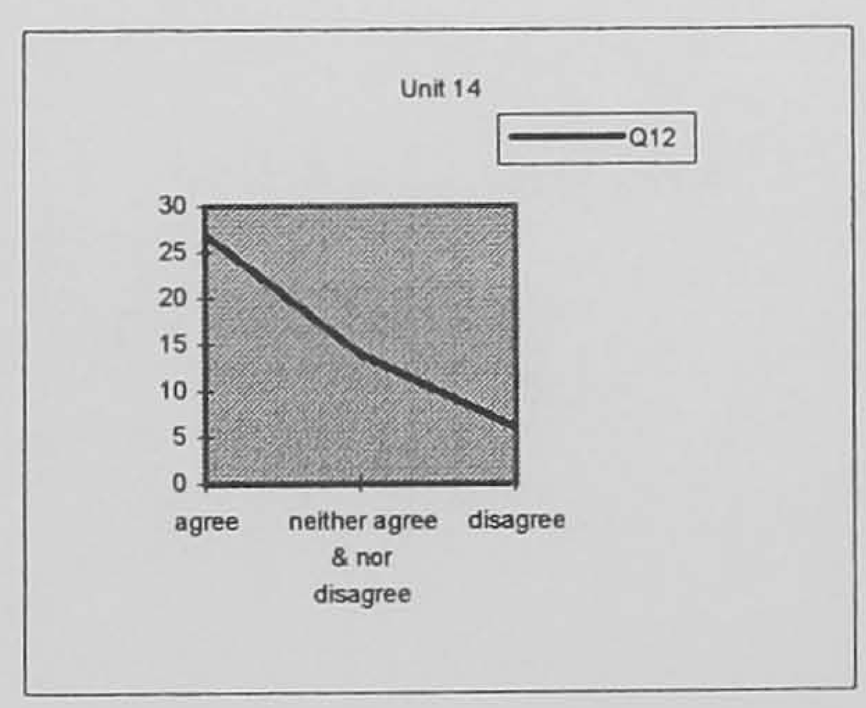
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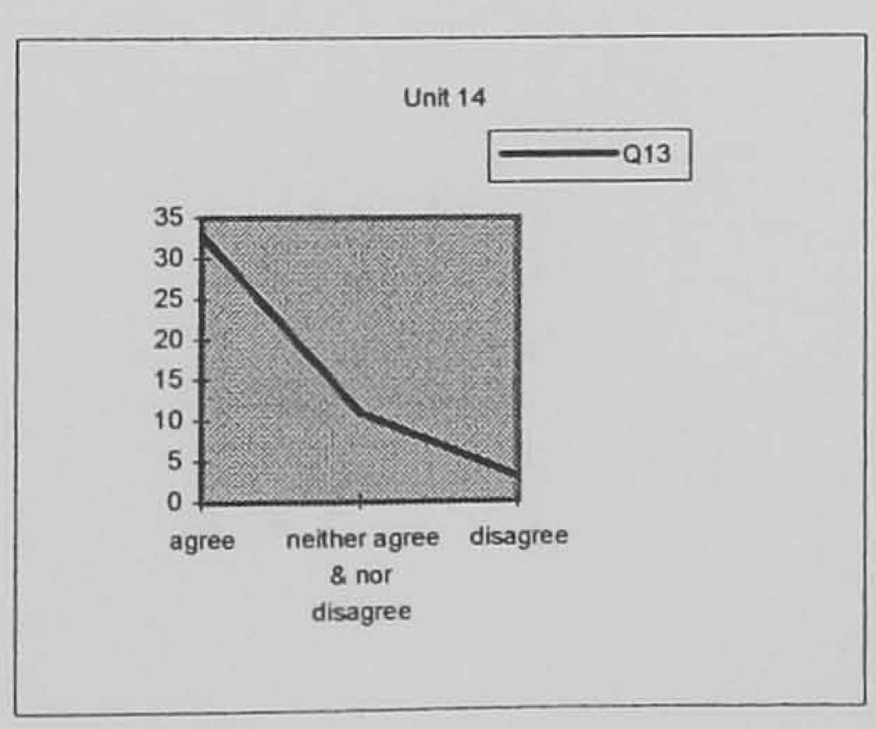
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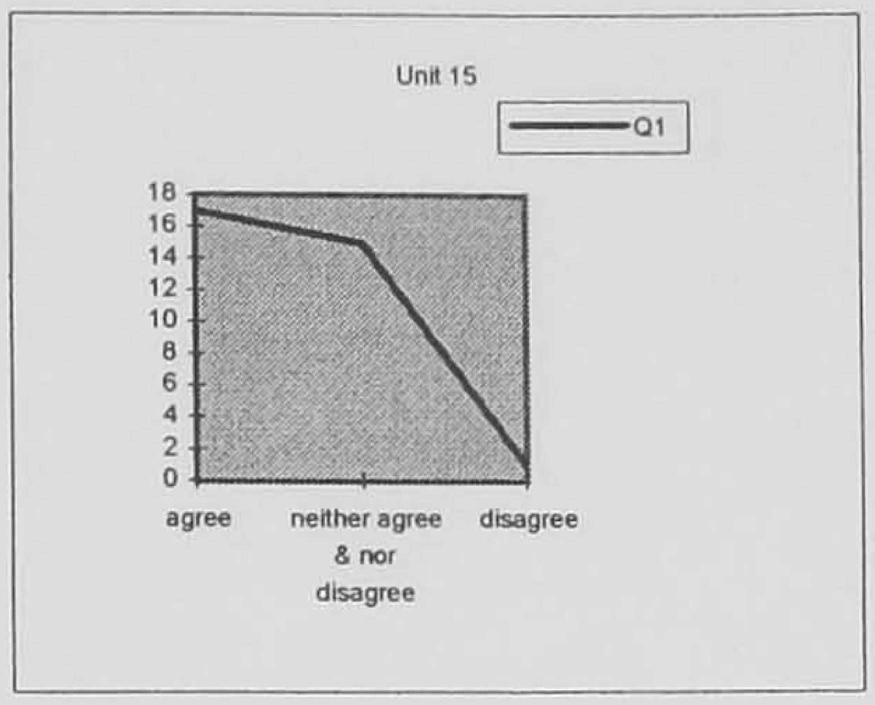
Unit 15



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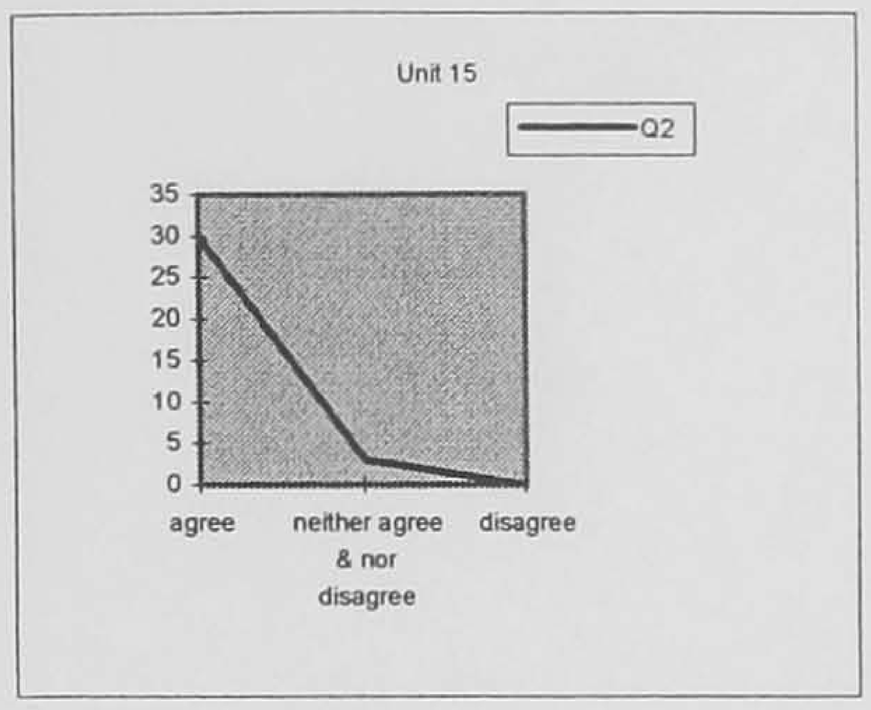

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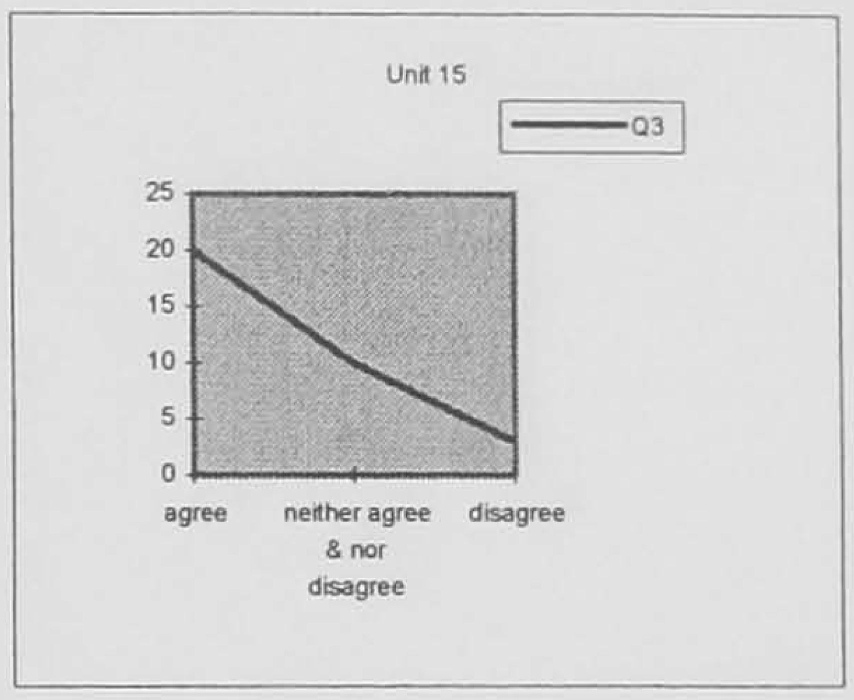
disagree



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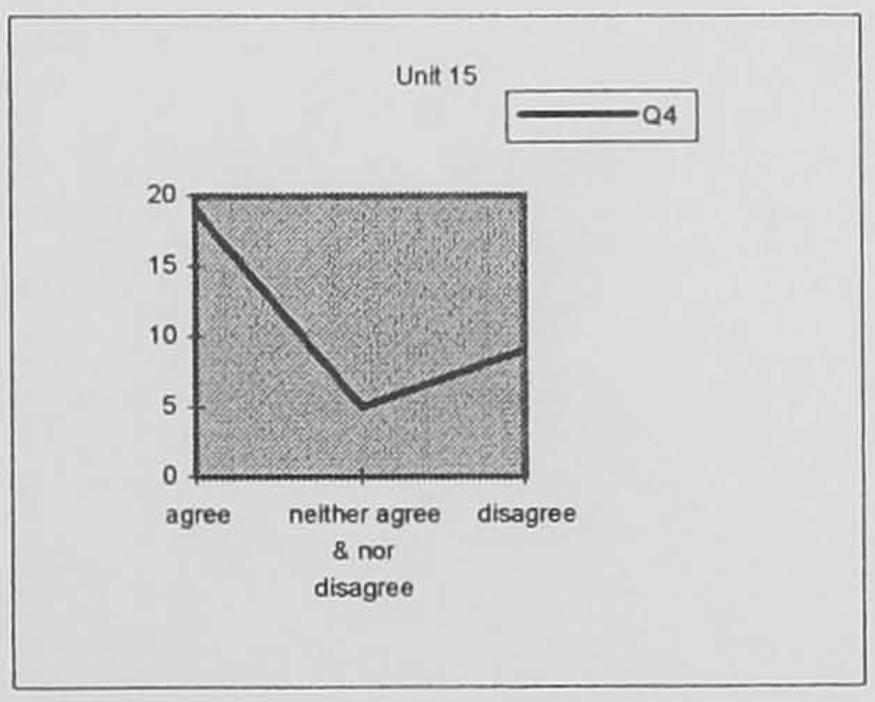

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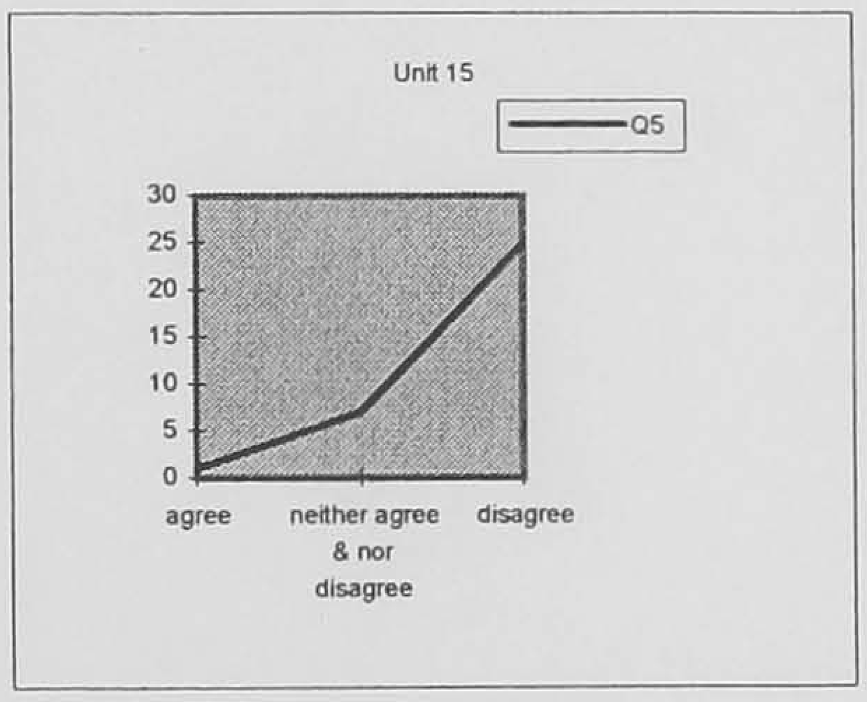

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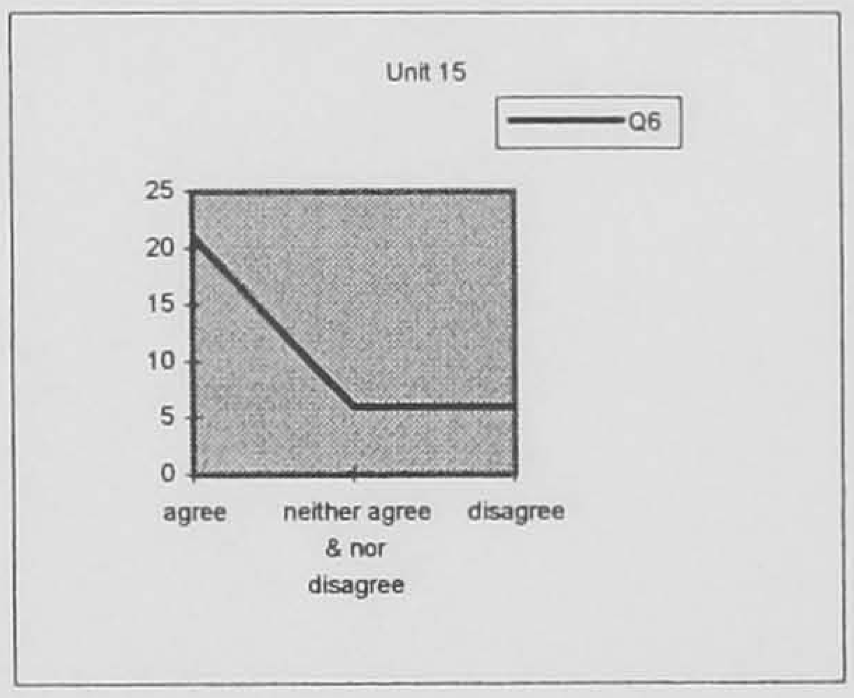

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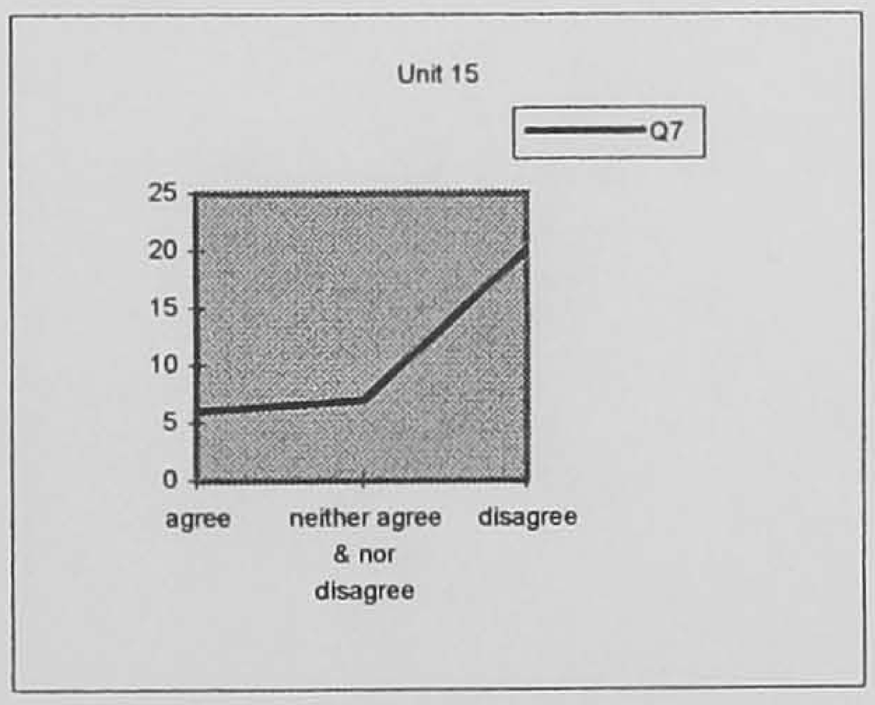

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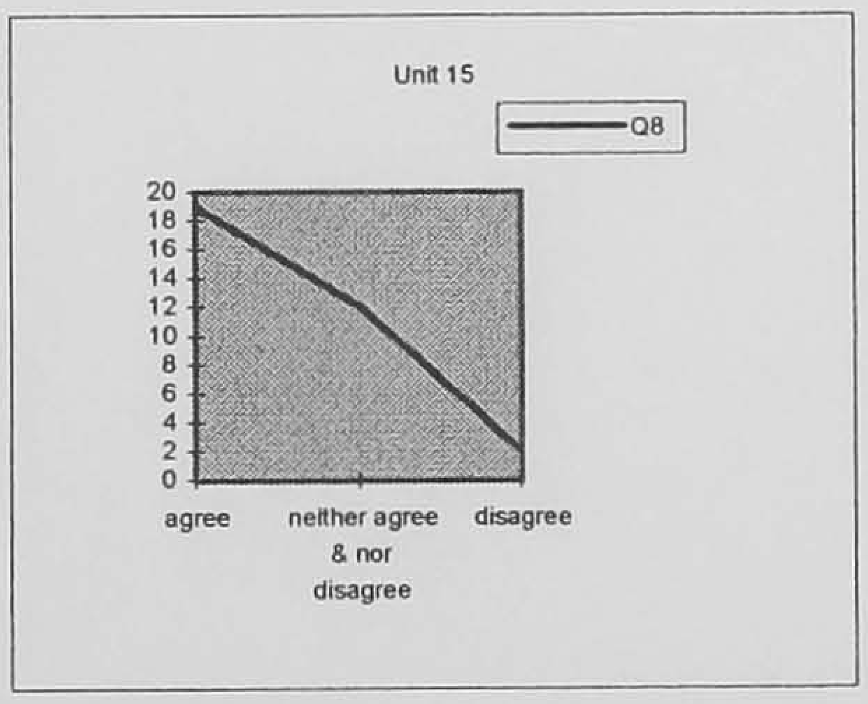

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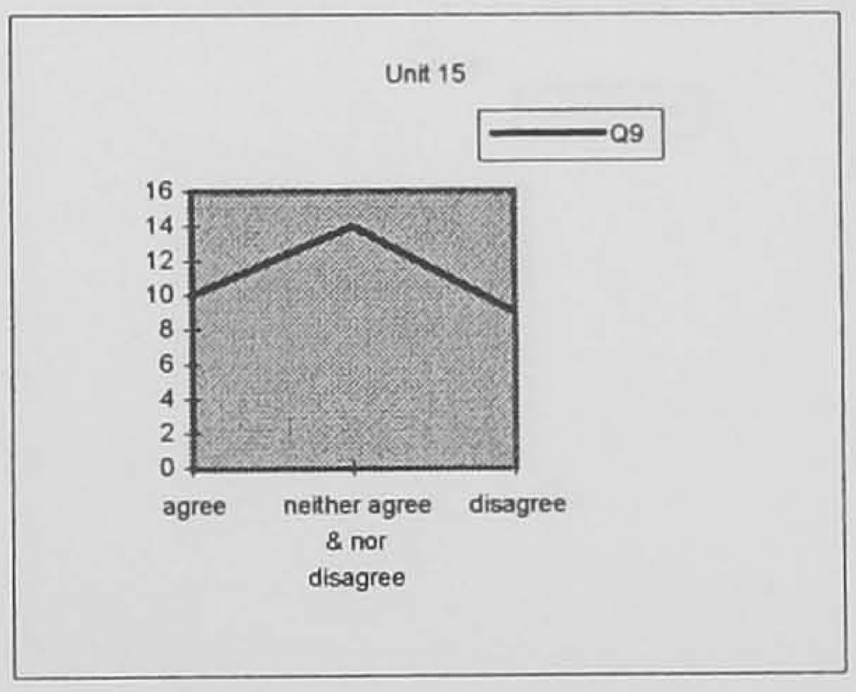
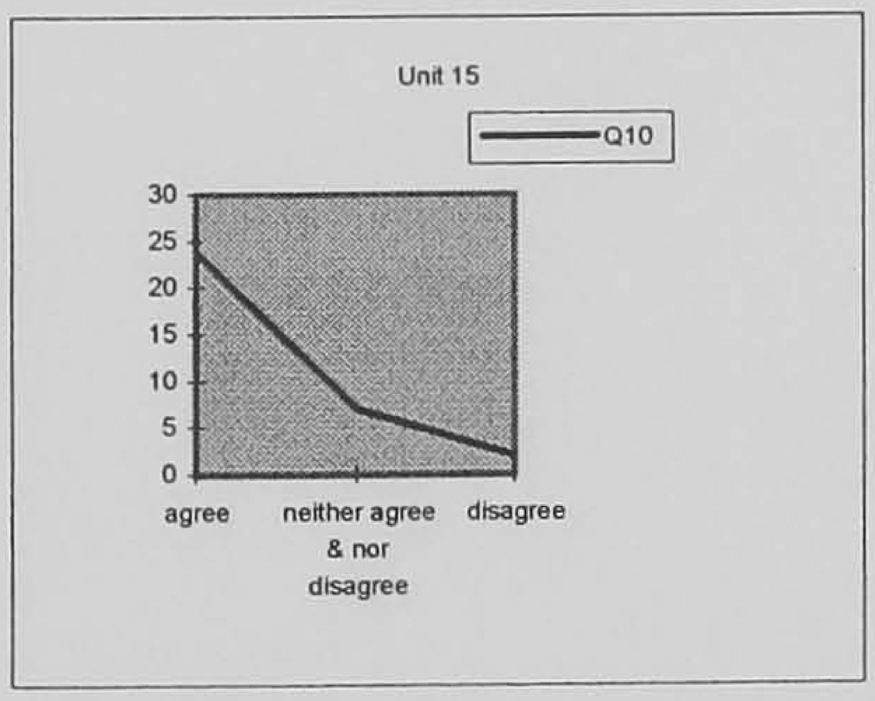
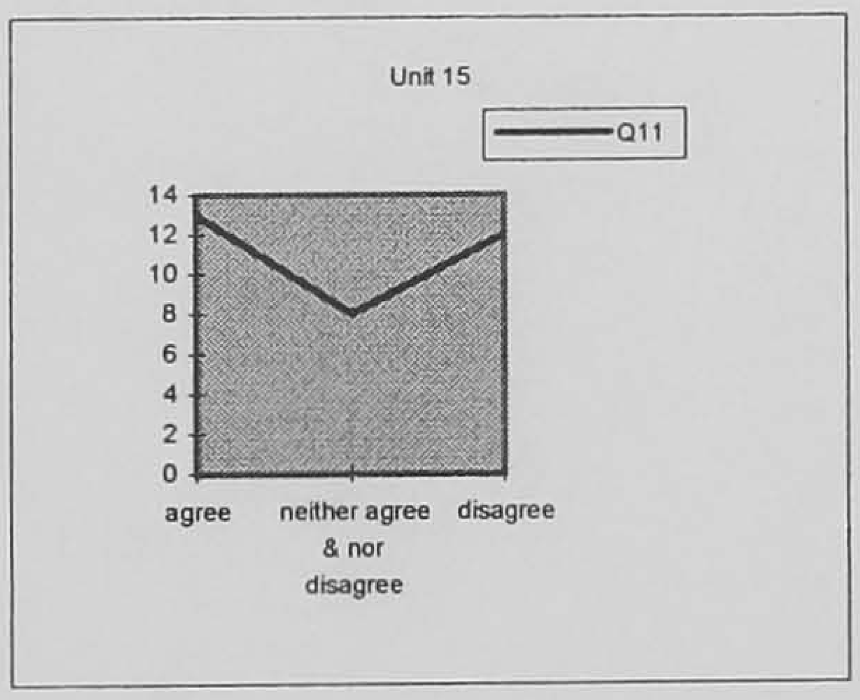
neither agree & nor disagree
disagree



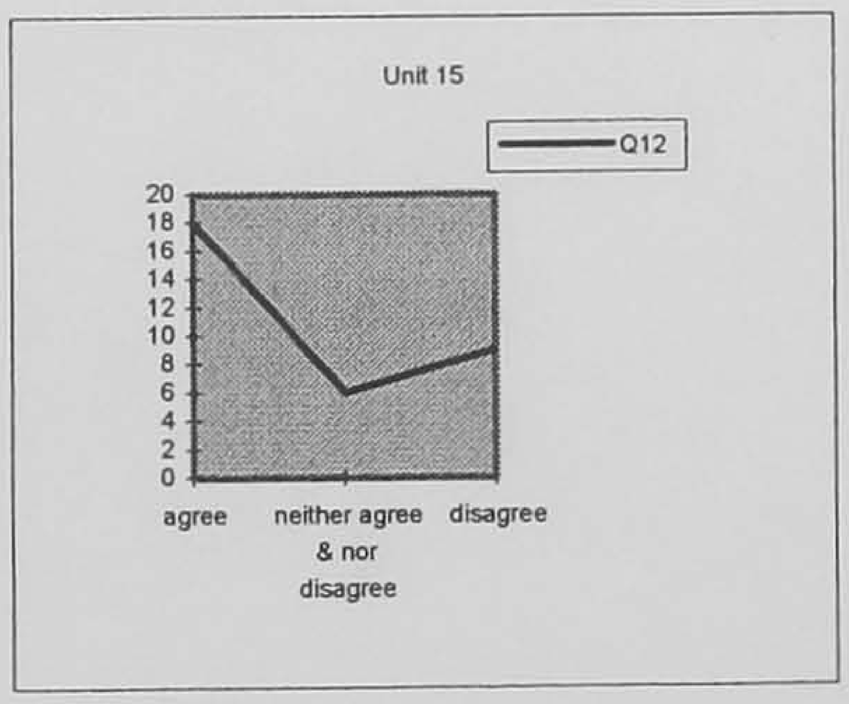
Unit 15
Q9
16 14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree



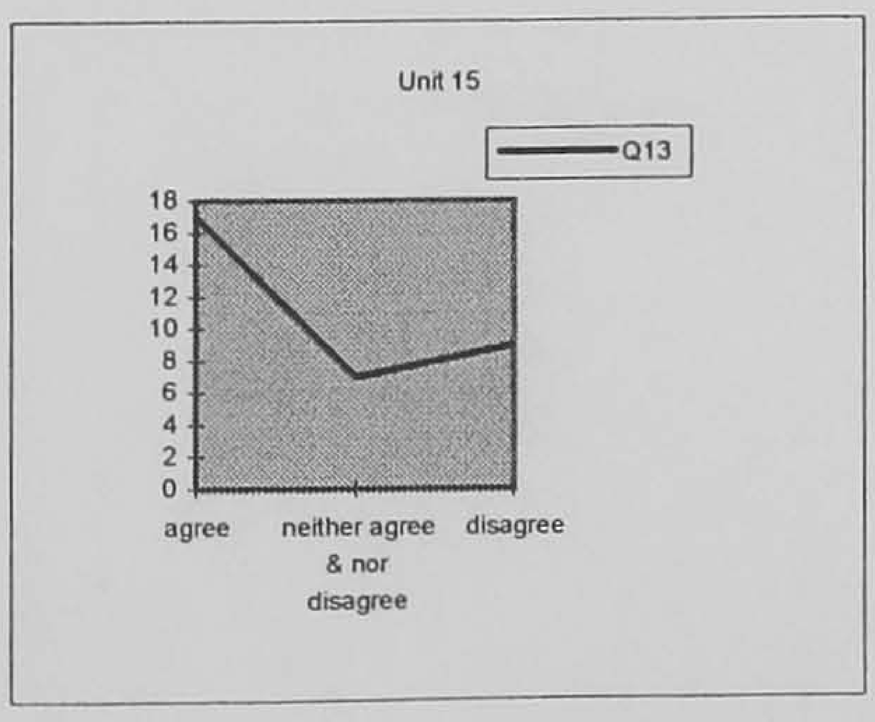
Unit 15
Q10
30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree



Unit 15
Q11
14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree

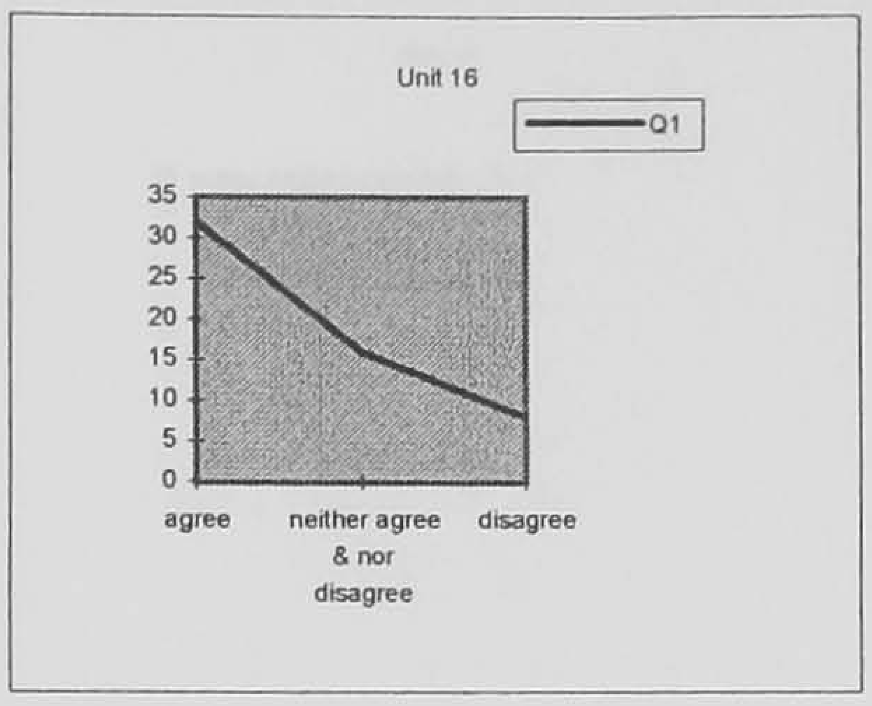


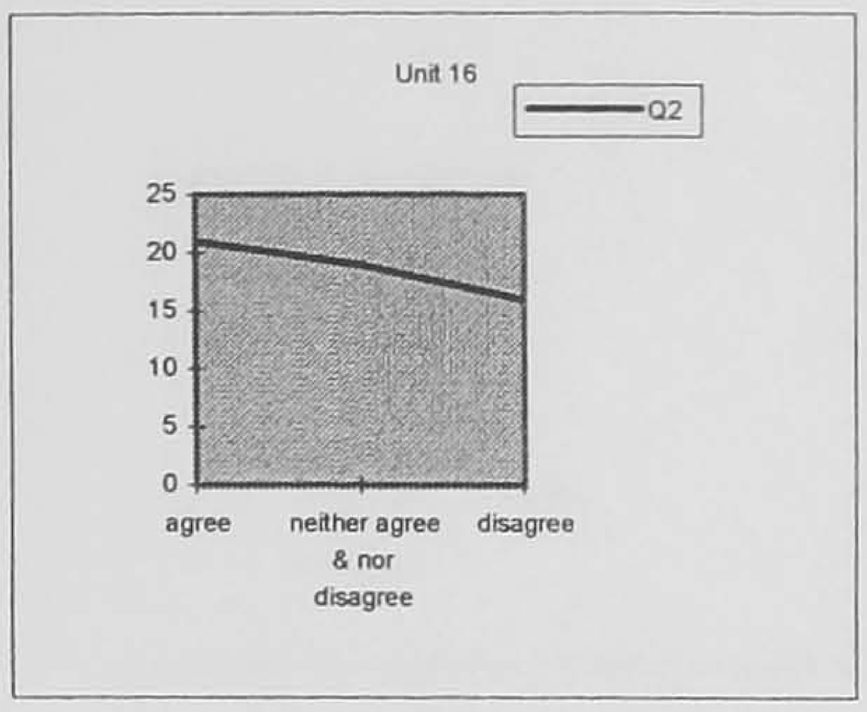
Unit 15
Q12
20 18 16 14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree

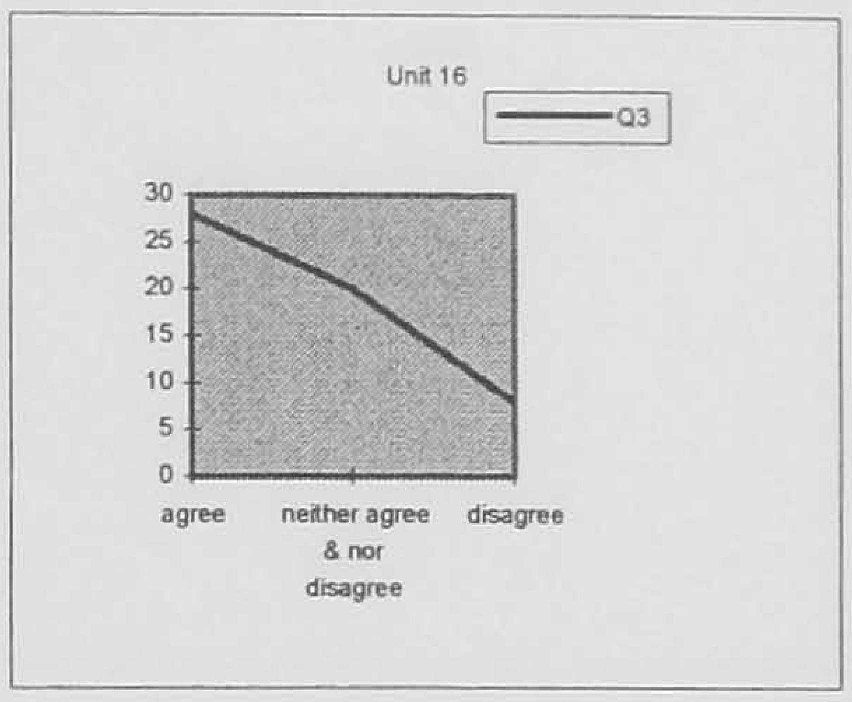


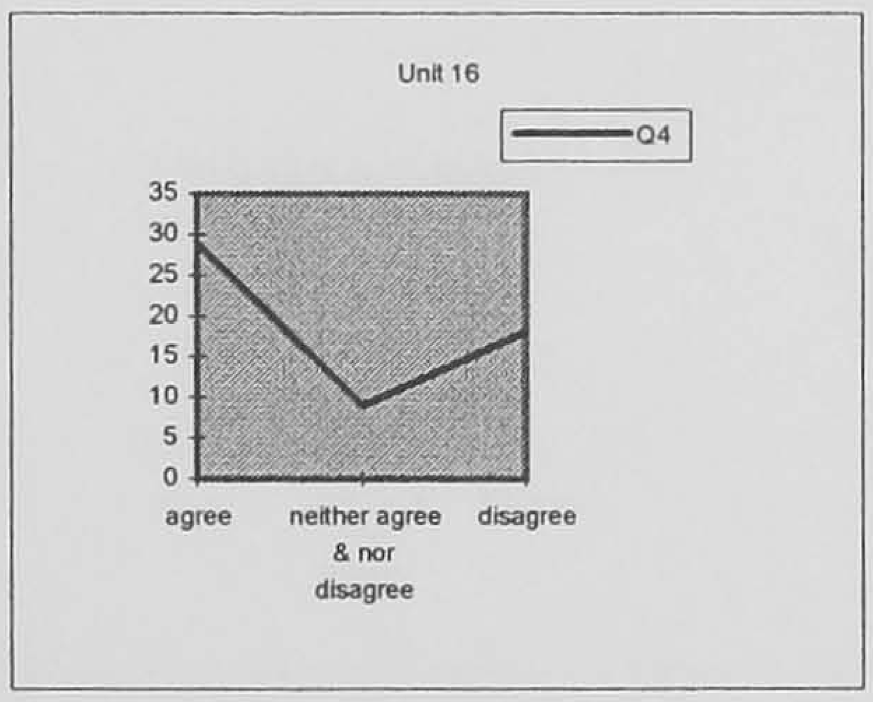
Unit 15
Q13
18 16 14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree

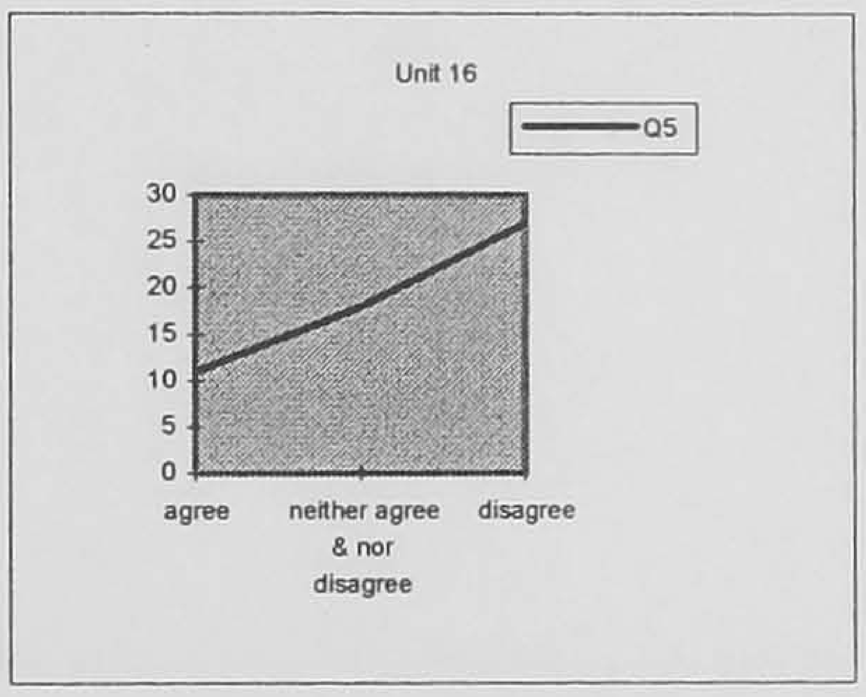
Unit 16

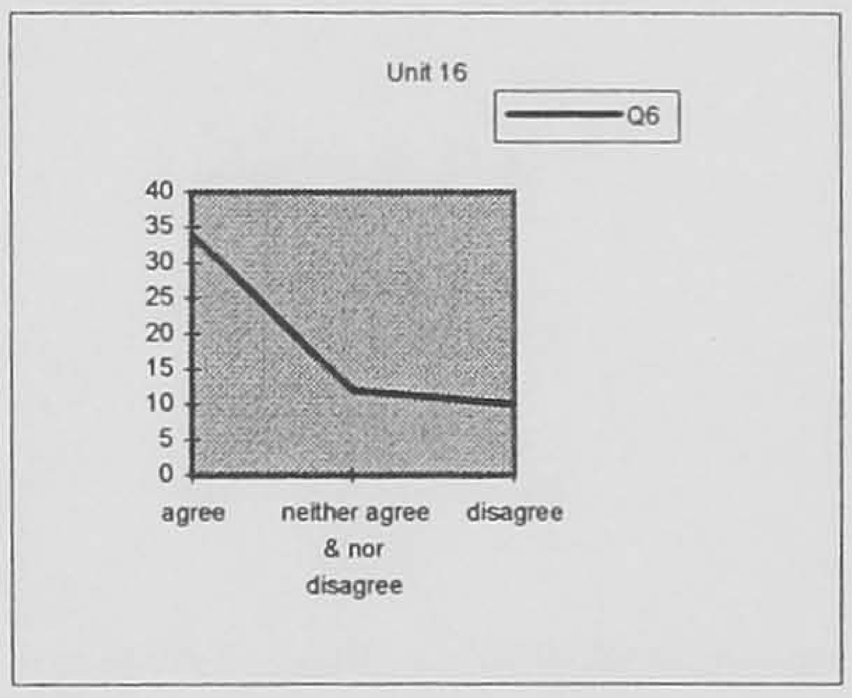

Unit 16
Q1
35 30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

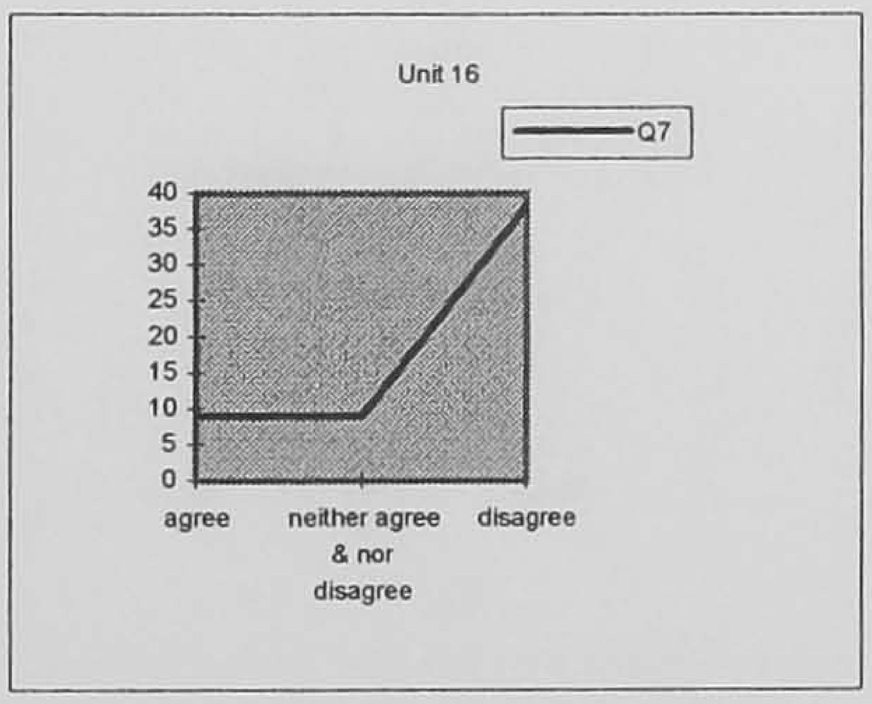

Unit 16
Q2
25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

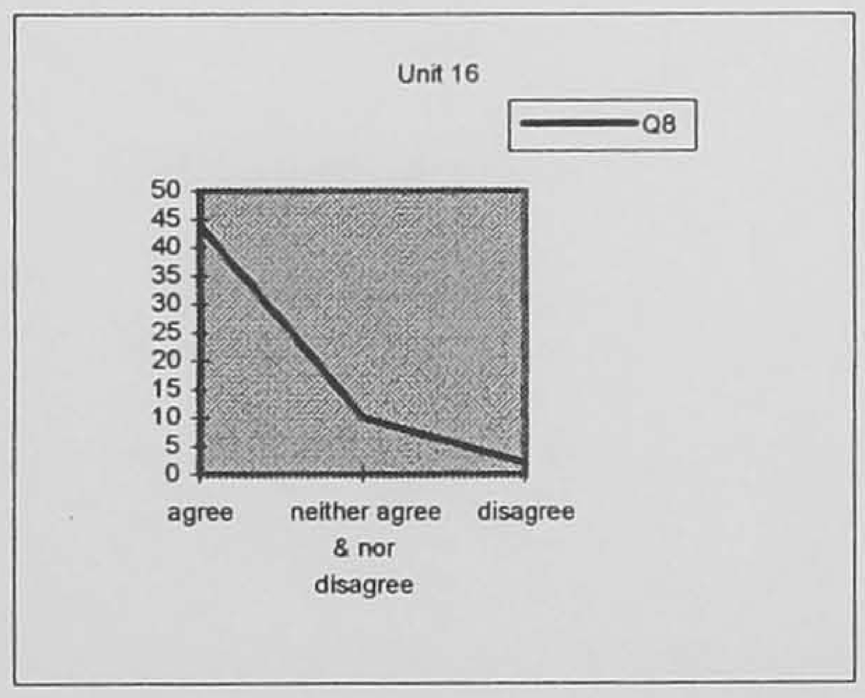

Unit 16
Q3
30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

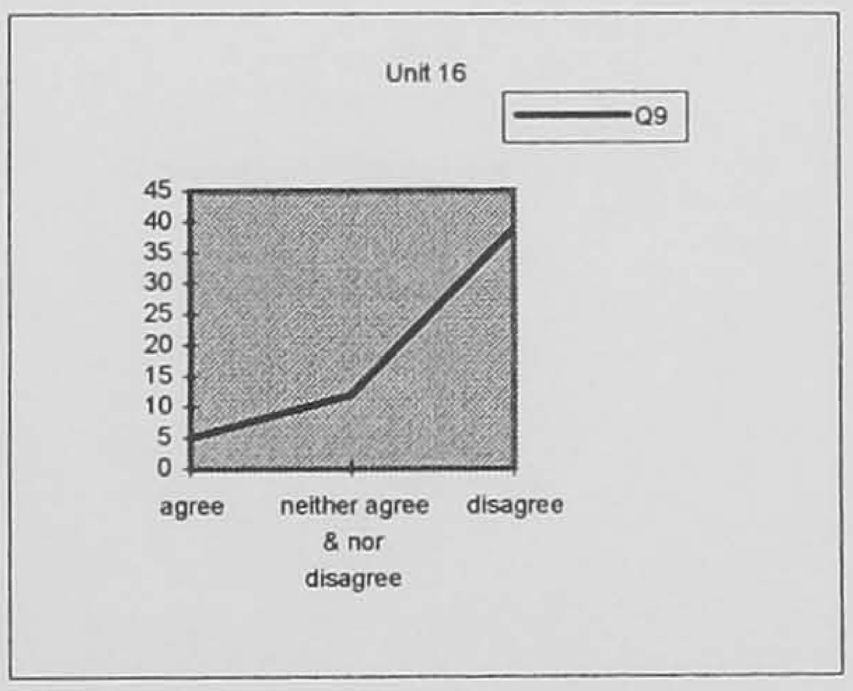

Unit 16
Q4
35 30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

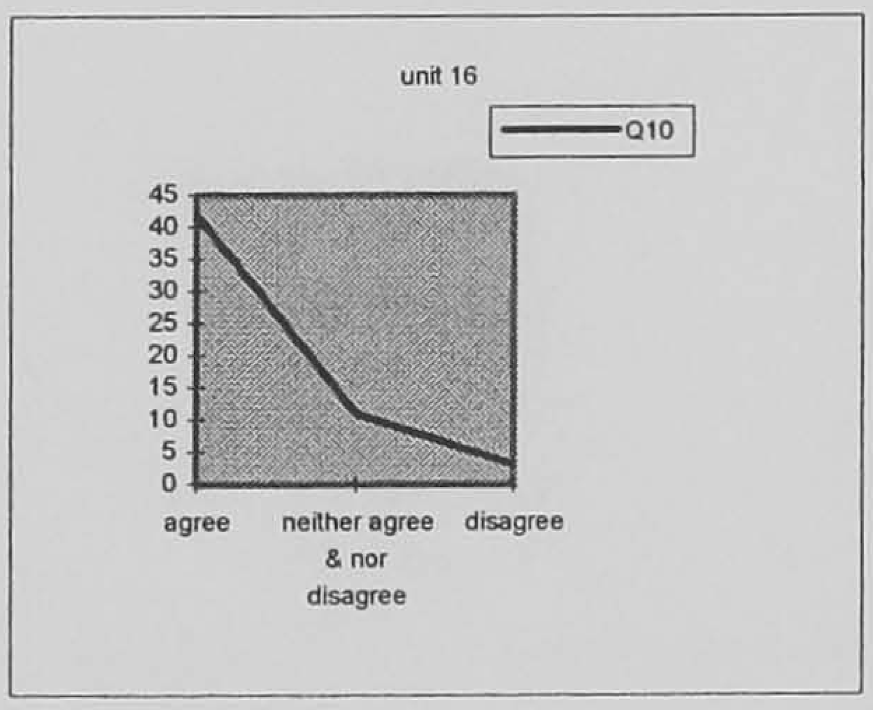

Unit 16
Q5
30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

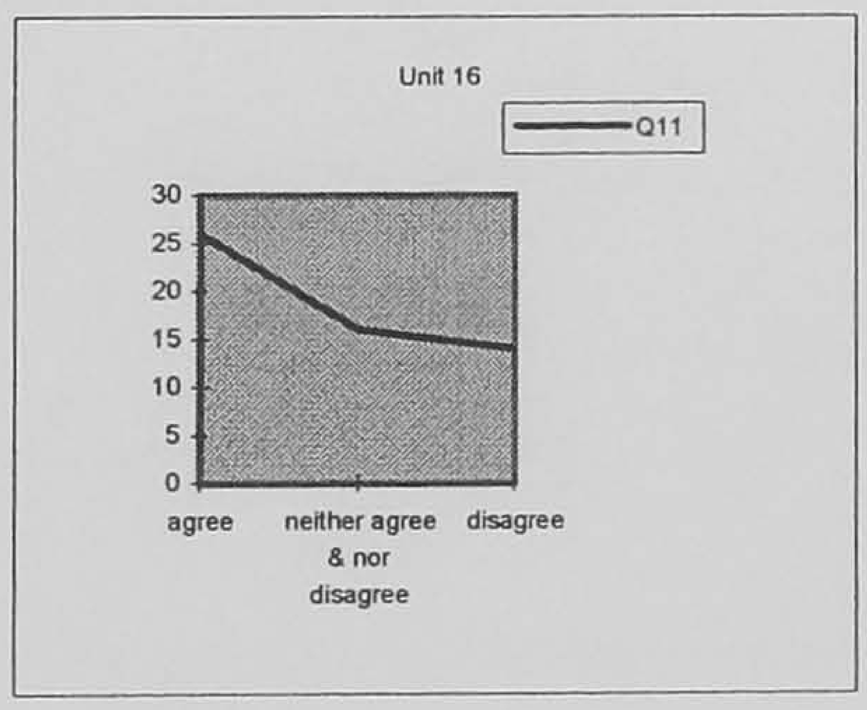

Unit 16
Q6
40 35 30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

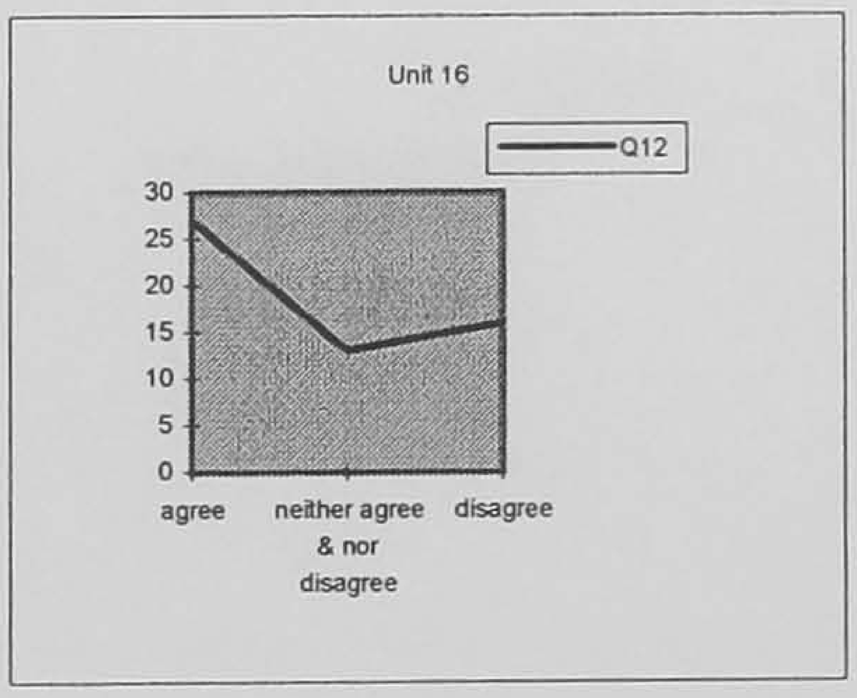

Unit 16
Q7
40 35 30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

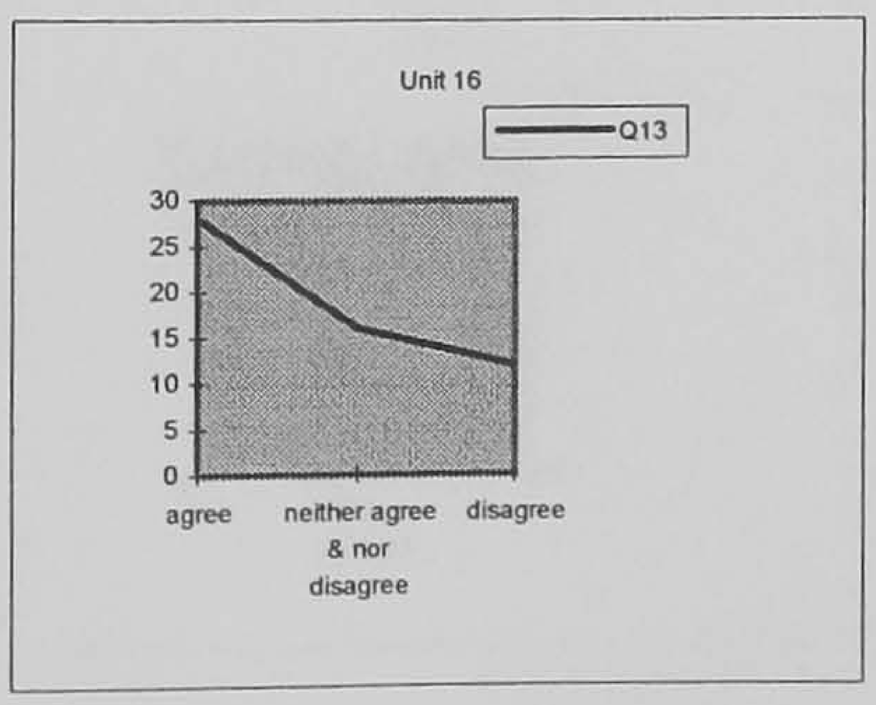

Unit 16
Q8
50 45 40 35 30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

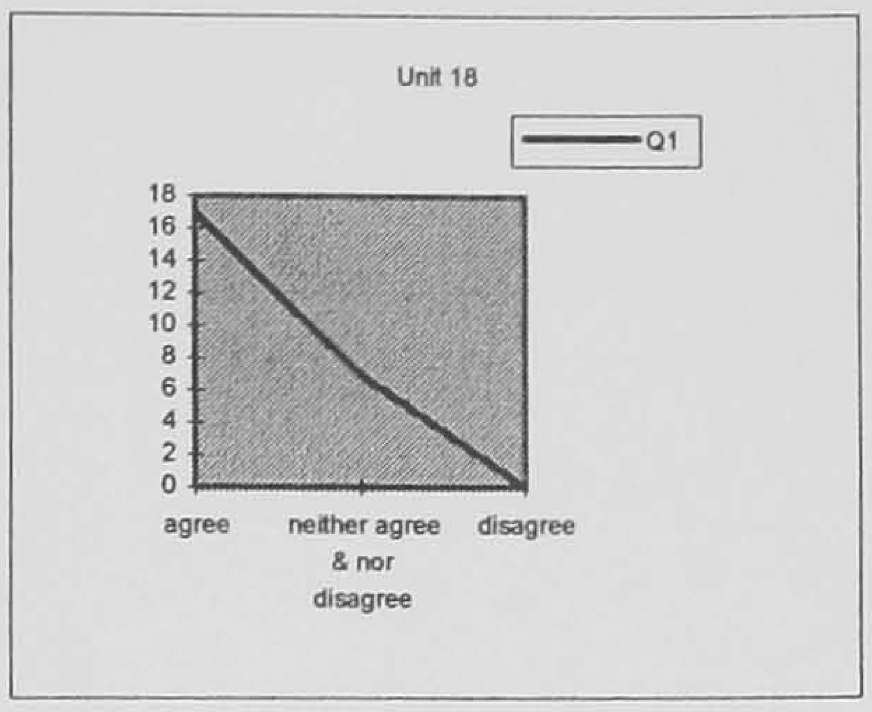

Unit 16
Q9
45 40 35 30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

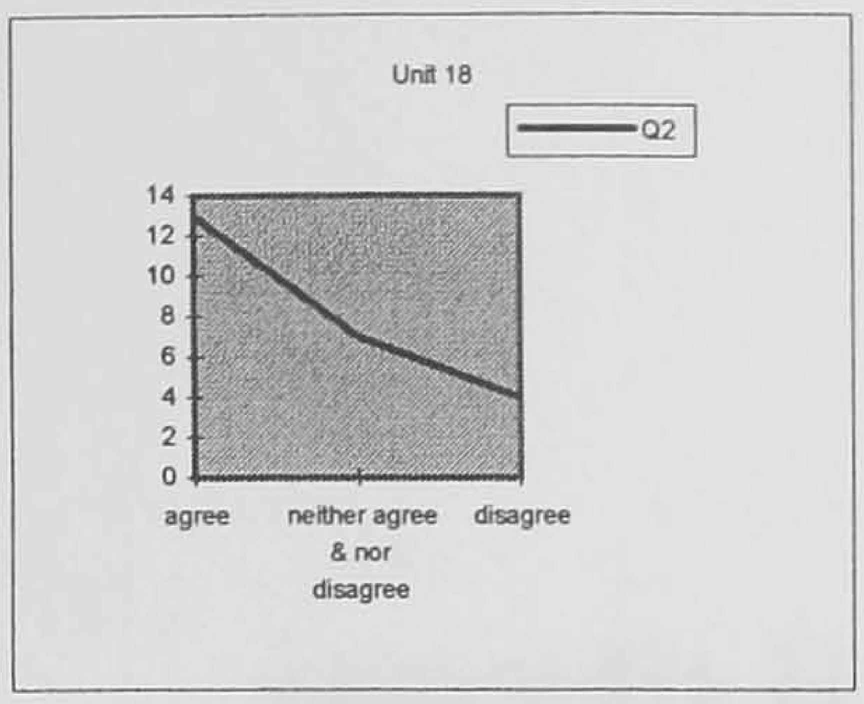

unit 16
Q10
45 40 35 30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

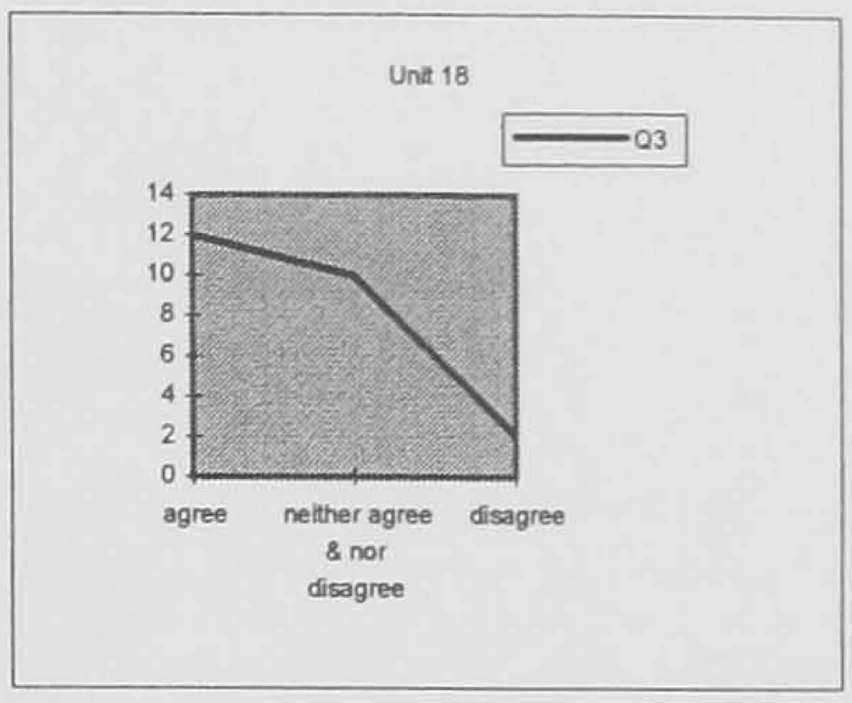

Unit 16
Q11
30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

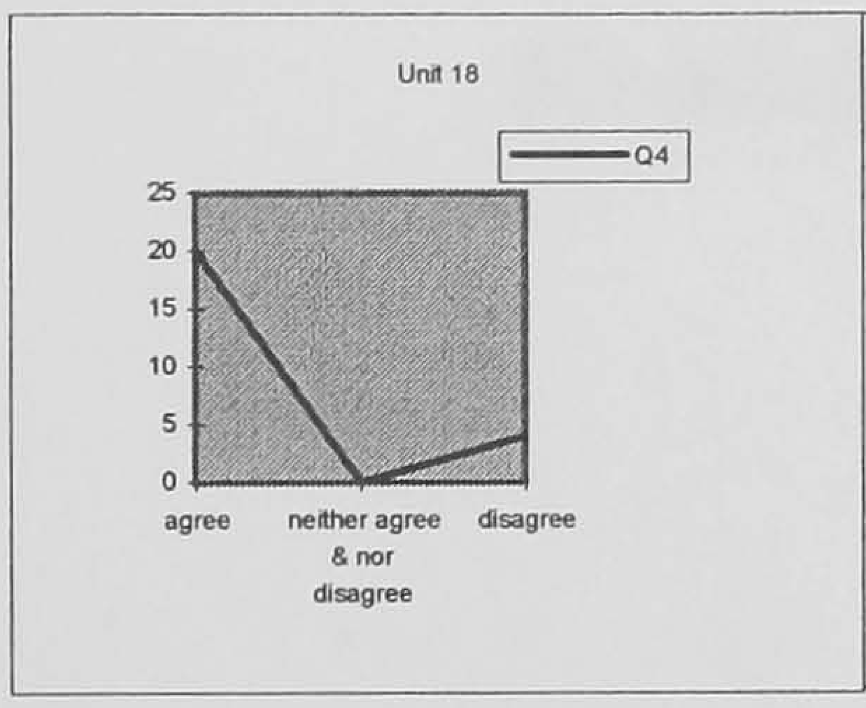

Unit 16
Q12
30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

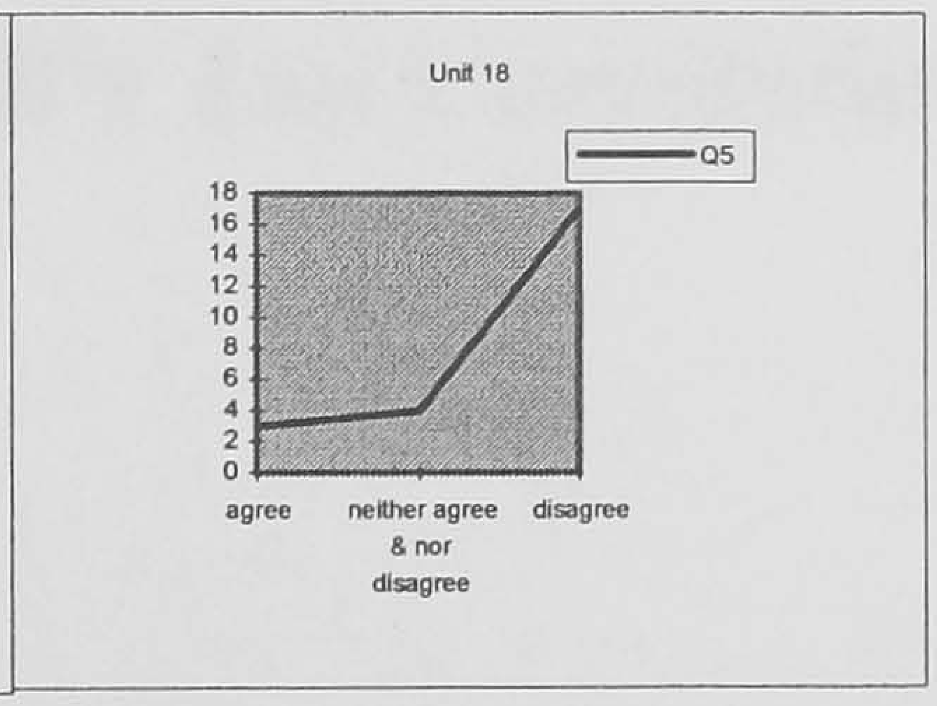

Unit 16
Q13
30 25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

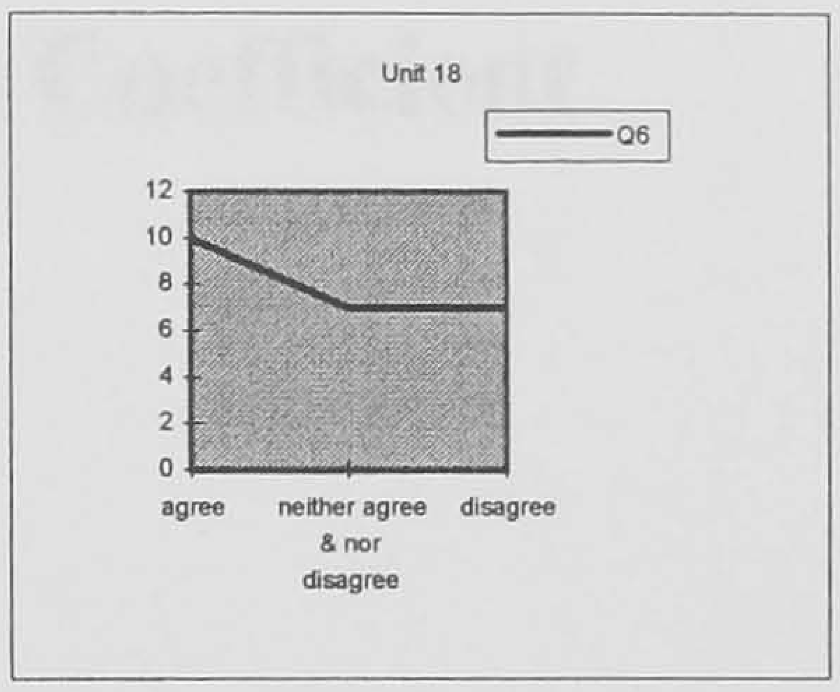

Unit 18
Q1
18 16 14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree

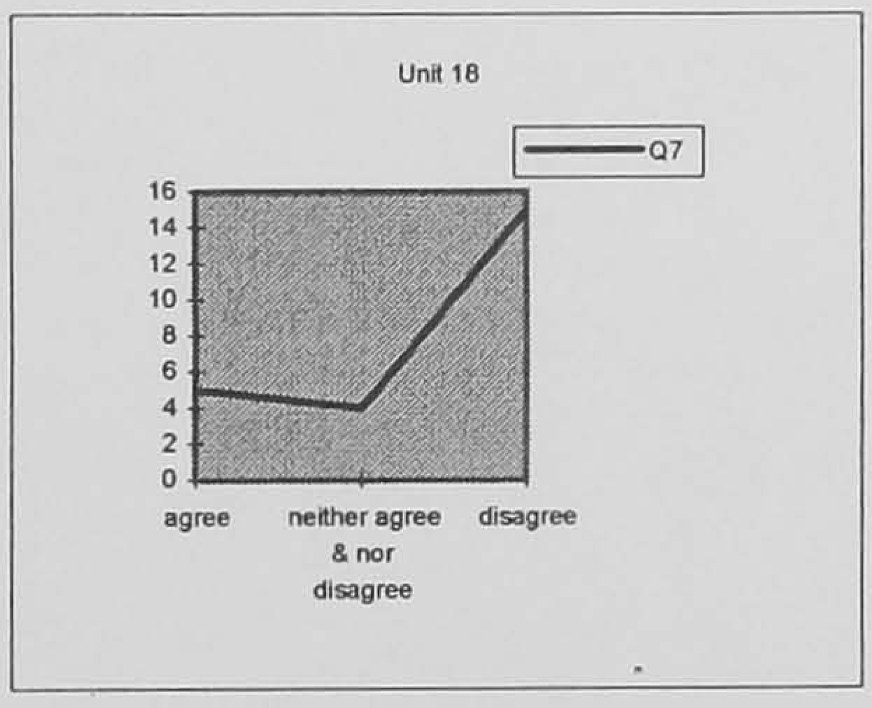

Unit 18
Q2
14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree

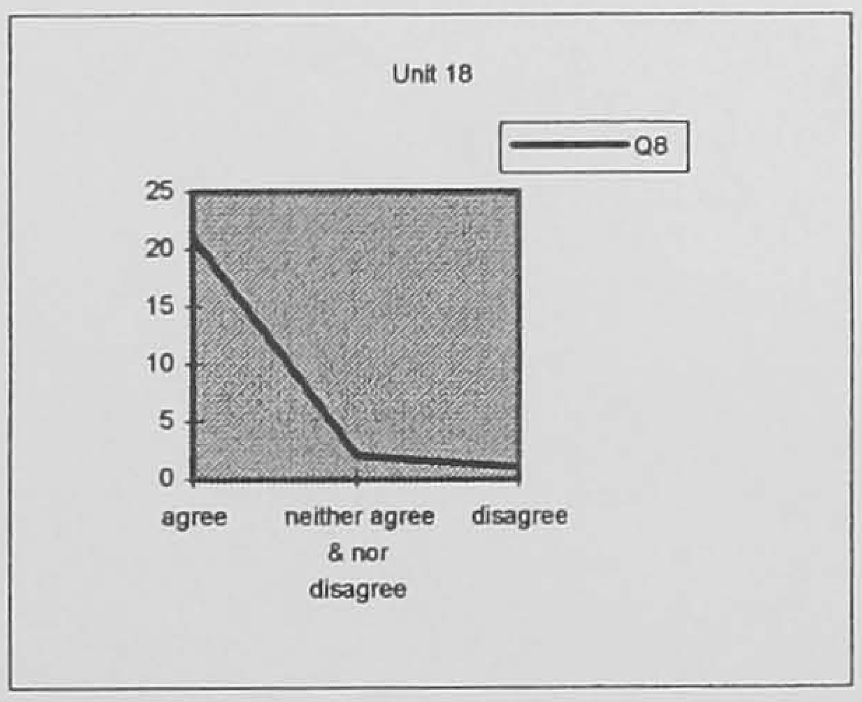

Unit 18
Q3
14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree

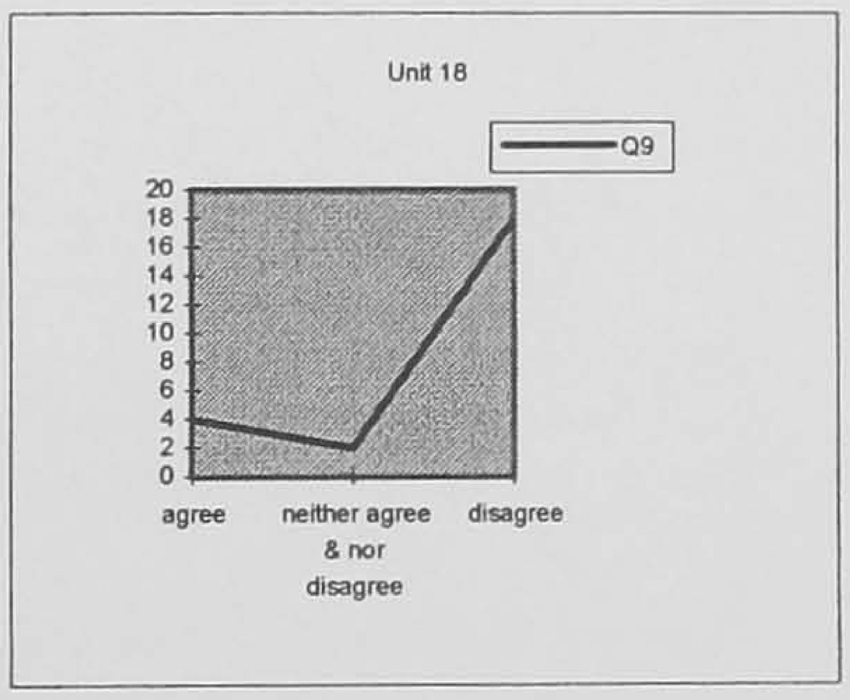

Unit 18
Q4
25 20 15 10 5 0
agree
neither agree & nor disagree
disagree

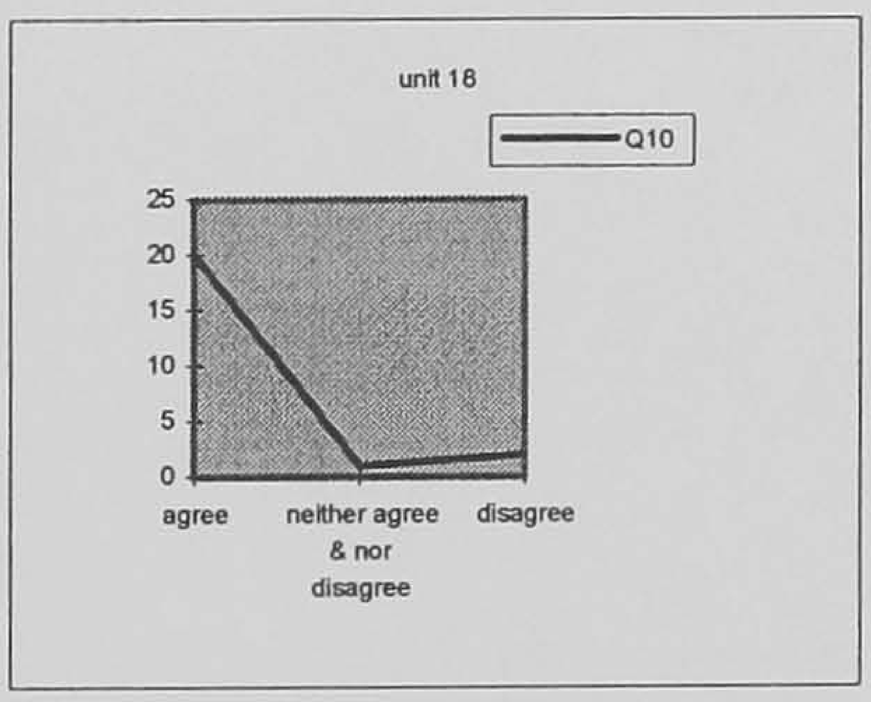

Unit 18
Q5
18 16 14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree

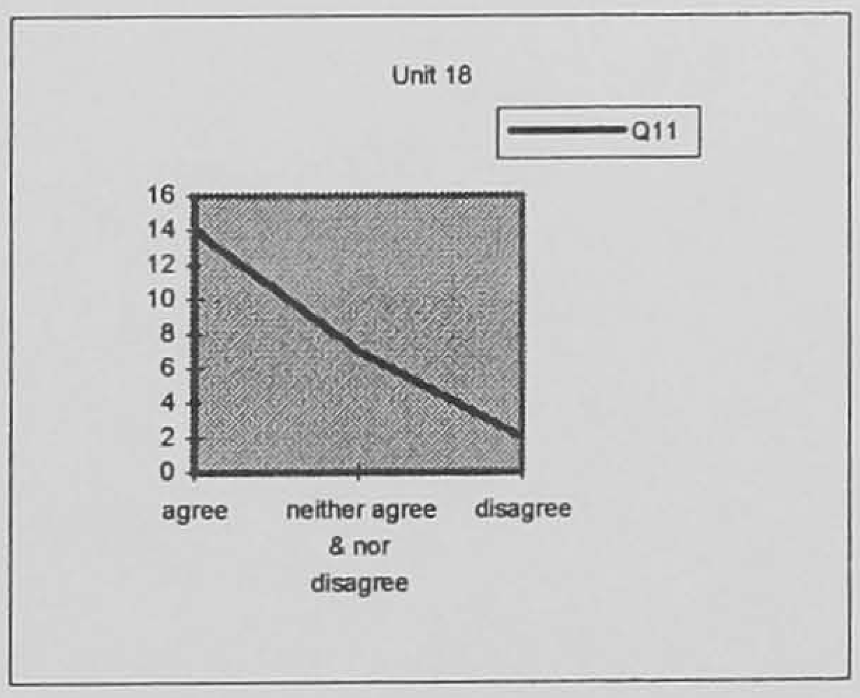

Unit 18
Q6
12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree

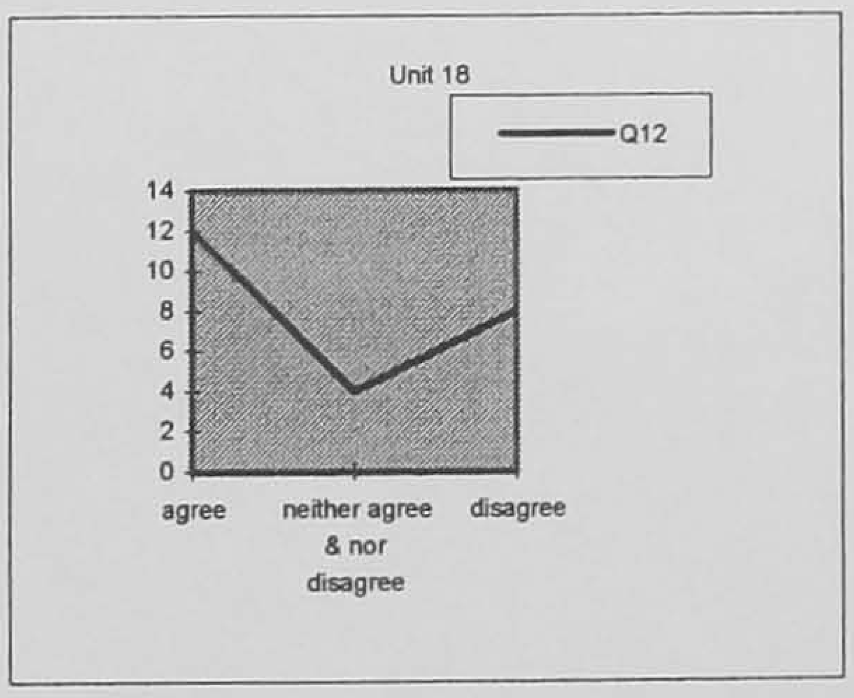

Unit 18
Q7
16 14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree

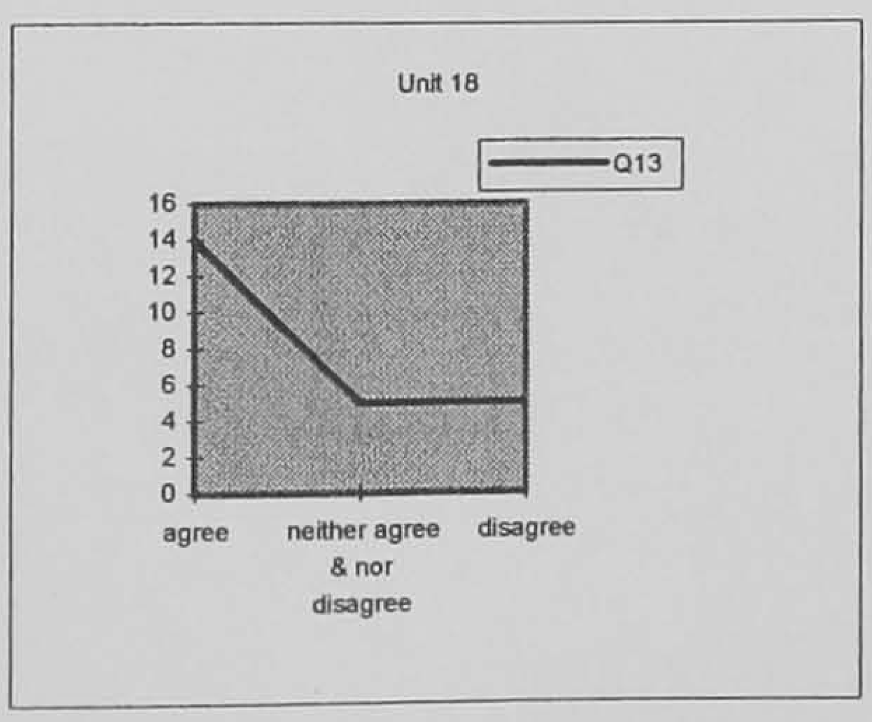

Unit 18
Q8
25 20 15 10 5 0
agree
neither agree & nor disagree
disagree


Unit 18
Q9
20 18 16 14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree


unit 18
Q10
25 20 15 10 5 0
agree
neither agree & nor disagree
disagree


Unit 18
Q11
16 14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree


Unit 18
Q12
14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree


Unit 18
Q13
16 14 12 10 8 6 4 2 0
agree
neither agree & nor disagree
disagree

Appendix H

Kendall's Tau Correlation Coefficient

Kendall's Tau Correlation Coefficient

Unit 1		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
	Q2												
	Q3	0.415**	-0.428**										
	Q4		0.524**	-0.361*									
	Q5	-0.349*											
	Q6		-0.451**	0.454**	-0.426**								
	Q7												
	Q8	0.364*											
	Q9		-0.324*										
	Q10								0.470**	-0.327*			
	Q11												
	Q12		0.436**	-0.369*	0.287*		-0.663**						
	Q13						-0.636**						0.685**

new Unit 1		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
	Q2												
	Q3	0.446**											
	Q4												
	Q5												
	Q6		-0.306*										
	Q7												
	Q8	0.383*				-0.330*							
	Q9			-0.339*					-0.384*				
	Q10	0.351*		0.343*		-0.298*		-0.340*	0.481**				
	Q11		0.429**			0.344*	-0.290*						
	Q12		0.328*		0.304*		-0.288*	-0.383**			0.380**	0.485**	
	Q13				0.468**							0.384**	0.610**

Unit 2		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
	Q2	-0.311*											
	Q3	0.360*											
	Q4	-0.434**	0.616**										
	Q5												
	Q6		-0.458**		-0.564**								
	Q7												
	Q8												
	Q9			-0.408**	0.321*								
	Q10							-0.306*	0.674**				
	Q11		0.349*		0.320*					0.414**			
	Q12		0.548**		0.479**		-0.494**	-0.459**					
	Q13		0.423**				-0.329*	-0.424**			0.372*	0.296*	0.561**

Unit 2-Taiwan		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
	Q2												
	Q3	0.420**											
	Q4	0.224*	0.218*										
	Q5												
	Q6			0.403**									
	Q7												
	Q8							-0.227*					
	Q9				0.268*			0.276*	-0.589**				
	Q10	0.349**				-0.250*			0.290**	-0.264*			
	Q11	-0.255*		-0.469**			-0.422**						
	Q12				0.248*		-0.386**					0.304**	
	Q13				0.279*		-0.242*				0.353**		0.557**

Unit 4		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
	Q2	0.485**											
	Q3	0.436**											
	Q4												
	Q5												
	Q6		-0.346*										
	Q7	0.323*		0.321*									
	Q8												
	Q9					0.312*							
	Q10												
	Q11		0.283*				-0.493**						
	Q12								0.371**				
	Q13				0.338*		-0.285*					0.290*	0.390**

Kendall's Tau Correlation Coefficient

Unit 5	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Q2												
Q3												
Q4												
Q5												
Q6				-0.390*								
Q7												
Q8							-0.535**					
Q9								-0.419**				
Q10							-0.353*					
Q11				0.327*		-0.353*	-0.346*			0.355*		
Q12				0.447**		-0.333*					0.580**	
Q13						-0.399*				0.464*	0.411**	0.490**

new Unit 5	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Q2												
Q3												
Q4												
Q5	-0.363*											
Q6		-0.505**										
Q7												
Q8			0.429*		-0.403*							
Q9												
Q10		0.550**			-0.451*							
Q11												
Q12				0.337*			-0.513**				0.350*	
Q13		0.335*					-0.361*					0.538**

Unit 6	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Q2												
Q3	0.589**											
Q4												
Q5			-0.552**									
Q6			0.482*									
Q7			0.511*									
Q8						0.513**						
Q9												
Q10												
Q11						-0.376*						
Q12						-0.497**	-0.586**				0.453*	
Q13			-0.417*			-0.452*	-0.692**					0.660**

Unit 8	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Q2	-0.308*											
Q3	0.384**											
Q4	-0.441**	0.390**										
Q5			-0.562**									
Q6		-0.386**	0.533**		-0.453**							
Q7	0.299*		0.335*			0.337*						
Q8							-0.564**					
Q9							0.331*	-0.578**				
Q10			0.302*		-0.543**	0.324*						
Q11		0.522**		0.332*	0.421**	-0.446**	-0.313*					
Q12	-0.407**	0.391**	-0.460**			-0.386**	-0.509**	0.397**			0.465**	
Q13		0.421**	-0.448**		0.305*	-0.401**	-0.326*	0.366*				0.593**

new Unit 8	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Q2												
Q3												
Q4												
Q5	-0.324*											
Q6		-0.384**			-0.285*							
Q7	-0.375*											
Q8	0.373*	0.286*					-0.283*					
Q9							0.372**	-0.290*				
Q10							-0.342*	0.498**				
Q11										-0.329*		
Q12							-0.463**					
Q13			0.319*				-0.336*					0.432**

Kendall's Tau Correlation Coefficient

		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Unit 9	Q2												
	Q3	0.478**											
	Q4		0.719**										
	Q5			-0.464*									
	Q6	0.388*	-0.467*		-0.480**								
	Q7					-0.388*	0.403*						
	Q8												
	Q9							0.435*	-0.493**				
	Q10		0.545**		0.595**		-0.455*		0.557**	-0.490**			
	Q11	-0.382*			0.370*								
	Q12		0.470**				-0.372*	-0.508**		-0.374*			
	Q13	-0.409*						-0.427*		-0.565**		0.526**	0.685**
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
new Unit 9	Q2												
	Q3	0.659**											
	Q4												
	Q5	-0.297*		-0.455**									
	Q6		-0.540**	0.312*		-0.332*							
	Q7												
	Q8	0.408*		0.493**									
	Q9							0.403**					
	Q10	0.303*				-0.297*			0.593**	-0.327*			
	Q11						-0.286*						
	Q12											0.342*	
	Q13												
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Unit 10	Q2	-0.322*											
	Q3	0.651**											
	Q4												
	Q5	-0.396**											
	Q6	0.484**		0.519**		-0.332*							
	Q7												
	Q8	0.563**	-0.371*	0.527**			0.409**						
	Q9	-0.369*		-0.367*	-0.313*				-0.479**				
	Q10	0.415**							0.568**	-0.351*			
	Q11	-0.486**	0.568**	-0.347*		0.424**	-0.350*		-0.432**		-0.304*		
	Q12	-0.337*	0.476**						-0.473**			0.454**	
	Q13		0.413**									0.523**	0.471**
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Unit 12	Q2												
	Q3												
	Q4		0.253*										
	Q5												
	Q6				-0.391**								
	Q7				-0.245*		0.327**						
	Q8						-0.282*	-0.554**					
	Q9							0.295*	-0.462**				
	Q10				-0.267*		0.271*						
	Q11		0.380**				-0.223*						
	Q12		0.237*		0.381**	0.232*	-0.250*	-0.237*			-0.231*		
	Q13							-0.309**			0.240*		0.239*
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Unit 13	Q2												
	Q3	0.360*											
	Q4		0.360*										
	Q5												
	Q6		-0.421**		-0.369*								
	Q7				-0.299*								
	Q8							-0.556**					
	Q9		-0.421*										
	Q10								0.424**				
	Q11		0.322*		0.528**	-0.291*	-0.514**						
	Q12		0.376*		0.442**		-0.611**	-0.361*	0.310*		0.331*	0.455**	
	Q13		0.508**		0.495**		-0.391**	-0.540**	0.330*		0.418**	0.423**	0.532**

Kendall's Tau Correlation Coefficient

Unit 14		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
	Q2												
	Q3	0.452**											
	Q4												
	Q5	-0.335**		-0.471**									
	Q6			0.260*		-0.398**							
	Q7												
	Q8							-0.353**					
	Q9	-0.245*				0.399**	-0.363**	0.372**	-0.419**				
	Q10				0.295*	-0.384**		-0.379**	0.425**	-0.402**			
	Q11		0.309*				-0.321*						
	Q12				0.255*								
	Q13				0.269*						0.327*		0.465**

Unit 15		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
	Q2												
	Q3	0.421**											
	Q4	-0.593**		-0.408**									
	Q5			-0.361*									
	Q6	0.330*											
	Q7					0.451**							
	Q8							-0.421**					
	Q9												
	Q10								0.410**				
	Q11		-0.309*										
	Q12		0.521**										
	Q13		0.387*	-0.304*	0.341*							-0.333*	0.408**

Unit 16		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
	Q2												
	Q3	0.516**											
	Q4		0.259*										
	Q5	-0.378**		-0.422**									
	Q6	0.238*	-0.242*		-0.252*								
	Q7												
	Q8	0.311**					0.351**						
	Q9								-0.310**				
	Q10	0.284*					0.250*		0.380**				
	Q11		0.314**						-0.337**				
	Q12				0.332**		-0.256*	-0.389**					
	Q13	0.237*	0.328**		0.573**			-0.339**	0.251*	-0.267*	0.323**		0.534**

Unit 18		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
	Q2												
	Q3	0.531**											
	Q4												
	Q5												
	Q6		-0.358*										
	Q7		-0.375*										
	Q8												
	Q9								-0.602**				
	Q10								0.464*	-0.477*			
	Q11			-0.400*									
	Q12			-0.355*					0.623**				
	Q13		-0.450*					0.362*					

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Q2	-2,4,-8,-10											
Q3	1,1a,2,2t,4,6,8, 9,9a,10,13,14 15,16,18	-1										
Q4	-2,2t,-8,-15	1,2,2t,8,9,12 13,16	1,-15									
Q5	-1,-5a,-8a,-9a -10,-16		-6,-8,-9,-9a,-14 -15,-16									
Q6	9,10,15,16	-1,-1a,-2,-4, -5a,-8,-8a, -9 -9a,-13,- 16,-18	1,2t,8,6, 9a,10, 14	-1,-2,-5,-9 -12,-13,-16	-8,-8a,-9a,-10 -14							
Q7	4,8,-8a	-18	4,6,8	-12,-13	-9,15	8,9,12						
Q8	1,1a,8a,9a	8a,-10 10,16	5a,9a,10		-1a,-5a	6, 10,-12,16	-2t,-5,-8,-8a,-12 -13,-14,-15					
Q9	-10,-14	-1, -13	-1a,-2,-10	2,2t,-10,2t	4,14	-14	2t,8,8a,9,9a, 12,14	-1a,-2t,-5,-8,-8a -9,-10,-12,-14 -16, -18				
Q10	1a,2t, 9a,-10, 16	5a,9	1a,8	9,-12,14	-1a,-2t,-5a ,-8, -9a,-14,	8,-9,12,16	-1a,-2,-5,-8a -14	1,1a,2,2t,,8a,9 9a,10,13,14 15,16,18	-1,-2t,-9,-9a, -10,-14,-18			
Q11	-2t, -9,-10	1a, 2,4,8,10,12 13,14,-15,16	2t,-10,-18	2,5,8,9,13	1a,8,10,-13	-1a,-2t,-4,-5,-8, -9a,-10-12, -13 -14	-5, -8	-10,-16	2	5,-8a,-10,		
Q12	-8,-10	1,1a,2,8,9 10,12,13,15 16	-1, -8,-18	1,1a,2,2t,5,5a 12,13,14,16	12	-1,-1a,-2,-2t-5 -6,-8,-9,-12,-13 -16	-1a,-2,-5a,-6,-8 -8a,-9, -12,-13 -16	4,8,-10,13 18	-9	1a,-12,13	1a,2t,5,5a,6,8, 9a, 10,13	
Q13	-9,16	2,5a,8,10 13,15,16,-18	-8,-6,8a,-15	1a,2t,4,13,14 15,16	8	-1,-2,-2t,-4, -5,-6,-8,-13	-2,-5a,-6,-8,-8a -9,-12,-13,-16, 18	8,13,16	-9,-16	2,2t,5,12,13, 14,16	1a,2,4,5,9 10,13,-15	1,1a,2,2t,4,5,5a 6,8,8a,9,10,12, 13,14,15,16

Summary

Correlations Between Fixed Response Questions

Where a correlation is significant for a pair of questions for any unit, the unit number is shown:

(a) In red - 1% significance
(b) In blue - 5% significance
(c) Sign (+ or -) - positive or negative correlation

["a" - revised unit; "t" - unit used in Taiwan]

Appendix I

A Summary of the Significant Correlation

A Summary of the Significant Correlations

Unit 1

(1) The problem was enjoyable: it has a positive association with "*satisfying*" (1%) and "*worked well together*" (5%) but has a negative association with "*learned nothing*" (5%).

(2) The problem was difficult: it has a positive association with "*new problem*" and "*could not solve problem myself* " (1%) but has a negative association with "*satisfying*", "*had enough previous knowledge*" at (1%) and "*did not share the work out evenly*" (5%).

(3) I found that solving this problem was satisfying: it has a positive association with "*had enough previous knowledge*" (1%) but has a negative association with "*new problem*" and "*could not solve problem myself*" (5%).

(4) The problem was completely new to me: it has a positive association with "*could not solve problem myself*" (5%) and a negative association with "*had enough previous knowledge*" (1%).

(6) I had enough previous knowledge to solve the problem: it has a negative association with "*could not solve problem myself*" and "*needed help from other members*" (1%).

(8) We worked well together as a group: it has a positive association with "*group discussion help*" (1%).

(9) We did not share the work out evenly in our group: it has a negative association with "*group discussion helpful*" (1%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

New Unit 1

(1) The problem was enjoyable: it has a positive association with "*satisfying*" (1%), "*worked well together*" and "*group discussion helpful*" (5%).

(2) The problem was difficult: it has a positive association with "*were not sure have the correct answer*"(1%) and "*could not solve problem myself*" (5%)but has a negative association with "*had enough previous knowledge*" (1%).

(3) I found that solving this problem was satisfying: it has a positive association with "*group discussion helpful*" (5%) but "*did not share the work out evenly*" (5%).

(4) The problem was completely new to me: it has a positive association with "*needed help from other members*" (1%) and "*could not solve problem myself*" (5%).

(5) I learned nothing from the probem: it has a positive association with "*were notsure had the correct answer*" (5%) but has a negative association with "worked well together" and "*group discussion helpful*" (5%)

(6) I had enough previous knowledge to solve the problem: it has a negative association with "*were not sure had the correct answer*" and "*could not solve problem myself*" (5%).

(7) I prefer solving problems on my own: it has a negative association wit*h"group discussion helpful*" (1%) and "*could not solve problem myself*" (1%).

(8) We worked well together as a group: it has a positive association with "*group discussion helpful*" (1%) but has a negative association with "*did not share the work out evenly*" (5%).

(10) I found the group discussion helpful: it has positive association with "*could not solve problem myself*" (1%).

(11) At the end, we were not sure we had the correct answer: it has a positiveasssociation with "*ould not solve problem myself* and "*needed help from other members*" (1%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

Unit 2

(1) The problem was enjoyable: it has a positive association with "*satisfying*" (5%) but has a negative association with "*difficult*" (5%) and "*new problem*" (1%).

(2) The problem was difficult: it has a positive association with "*new problem*", "*could not solve problem myself*" and "*needed help from other members*" (1%) and "*were not sure had the correct answer*" (5%) but has a negative association with "*had enough previous knowledge*" (1%).

(3) I found that solving this problem was satisfying: it has a negative association with "*did not share the work out evenly*" (1%).

(4) The problem was completely new to me: it has a positive association with "*could not solve problem myself*" (1%), "*did not share the work out evenly*" and "*were not sure had the correct answer*" (5%) but has a negative association with "*had enough previous knowledge*" (1%).

(6) I had enough previous knowledge to solve the problem: it has a negative association with "*could not solve problem myself*" (1%) and "*needed help from other members*" (5%)

(7) I prefer solving problems on my own: it has a negative association with "*group discussion helpful*" (1%) and "*could not solve problem myself*" and "*needed help from other members*" (1%)

(8) We worked well together as a group: a positive association with "*group discussion helpful*" (1%).

(9) We did not share the work out evenly in our group: it has a positive association with "*were not sure had the correct answer*" (1%).

(10) I found the group discussion helpful: it has positive association with "*needed help from other members*" (5%).

(11) At the end, we were not sure we had the correct answer: it has a positive asssociation with "*needed help from other members*" (5%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

Unit 2 Taiwan

(1) The problem was enjoyable: it has a positive association with "*satisfying*", "*group discussion helpful*" (1%) and "new problem" but has a negative association with "*were not sure had the correct answer*" (5%).

(2) The problem was difficult: it has a positive association with "*new problem*" (5%).

(3) I found that solving this problem was satisfying: it has a positive association with "*had enough previuos knowledge*" (1%) but a negative association with "*were not sure had the correct answer*" (1%).

(4) The problem was completely new to me: it has a positive association with "*did not share the work out evenly*", "*could not solve problem myself*" and "*needed help from other members*" (5%).

(5) I learned nothing from the probem: a negative association with "*group discussion helpful*" (5%).

(6) I had enough previous knowledge to solve the problem: it has a negative association with "*could not solve problem myself*" (1%) and "*needed help from other members*" (5%).

(7) I prefer solving problems on my own: it has a negative association with "*were not sure had the correct answer*", "*could not solve problem myself*" (1%) and "*needed help from other members*" (5%).

(8) We worked well together as a group: it has a positive association with "*group discussion helpful*" (1%) but has a negative association with "*did not share the work out evenly*" (1%)..

(9) We did not share the work out evenly in our group: it has a negative association with "*group discussion helpful*" (5%).

(10) I found the group discussion helpful: it has a positive association with "*needed help from other members*" (1%).

(11) At the end, we were not sure we had the correct answer: it has a positive asssociation with "*could not solve problem myself*" (1%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

Unit 4

(1) The problem was enjoyable: it has a positive association with "*difficult*", "*satisfying*" at 1%and "*prefer solving problem myself*" (5%).

(2) The problem was difficult: it has a positive association with "*were not sure had the correct answer*" (5%) but has a negative association with "*had enough previous knowledge*" (5%).

(3) I found that solving this problem was satisfying: it has a positive association with "*prefer solving problem myself*" (5%).

(4) The problem was completely new to me: it has a positive association with "*needed help from other members*" (5%).

(5) I learned nothing from the problem: it has a positive association with "*did not share the work out evenly*" (5%).

(6) I had enough previous knowledge to solve the problem: it has a negative association with "*were not sure had the correct answer*" (1%) and "*needed help from other members*" (5%).

(8) We worked well together as a group: it has a positive association with "*could not solve problem myself*" (1%).

(11) At the end, we were not sure we had the correct answer: it has a positive asssociation with "*needed help from other members*" (5%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

Unit 5

(4) The problem was completely new to me: it has a positive association with "*could not solve problem myself*" (1%) and "*were not sure had the correct answer*" (5%) but has a negative association with "*had enough previous knowledge*" (5%).

(6) We worked well together as a group: it has a negative association with "*were not sure had the correct answer*", "*could not solve problem myself*"and "*needed help from other members*" at 5%.

(7) I prefer solving problems on my own: it has a negative association with "*worked well together*" (1%), "*group discussion helpful*" and "*were not sure had the correct answer*" (5%).

(8) We worked well together as a group: it has a negative association with "*did not share the work out evenly*" (1%).

(10) I found the group discussion helpful: it has a positive association with "*wer not sure had the correct answer*" and "*needed help from other members*" (5%).

(11) At the end, we were not sure we had the correct answer: it has a positive asssociation with "*could not solve problem myself*" and "*needed help from other members*" (1%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

New Unit 5

(1) The problem was enjoyable: it has a negative association with *"learned nothing"* (5%).

(2) The problem was difficult: it has a positive association with *"group discussion helpful"* (1%) and *"needed help from other members"* (5%) but has a negative association with *"had enough previous knowledge"* (1%).

(3) I found that solving this problem was satisfying: it has a positive association with *"worked well together"* (5%).

(4) The problem was completely new to me: it has a positive association with *"could not solve problem myself"* (5%).

(5) I learned nothing from the problem: it has a negative association with *"worked well together"* and *"group discussion helpful"* (5%).

(7) I prefer solving problems on my own: it has a negative association with *"could not solve problem myself"* (1%) and *"needed help from other members"* (5%).

(11) At the end, we were not sure we had the correct answer: it has a positive asssociation with *"could not solve problem myself"* (5%).

(12) I could not have solved the peoblem by myself: it has a positive association with *"needed help from other members"* (1%).

Unit 8

(1) The problem was enjoyable: it has a positive association with *"satisfying"* (1%) and *"prefer solving problem myself"* (5%) but has a negative association with *"new problem"*, *"could not solve problem myself"* at 1% and *"difficult"* (5%).

(2) The problem was difficult: it has a positive association with *"new problem"*, *"were not sure had the correct answer"*, *"could not solve problem myself"* and *"needed help from other members"* at 1% but has a negative association with *"had enough previous knowledge"* (1%).

(3) I found that solving this problem was satisfying: it has a positive association with *"had enough previous knowledge"* (1%) and *"prefer solving problem myself"*, *"group discussion helpful"* at 5% but has a negative association with *"learned nothing"*, *"could not solve problem myself"* and *"needed help from other members"* at 1%.

(4) The problem was completely new to me: it has a positive association with *"were not sure had the correct answer"* (5%).

(5) I learned nothing from the problem: it has a positive association with *"were not sure had the correct answer"* (1%) and *"needed help from other members"* (5%) but has a negative association with *"had enough previous knowledge"* and *"group discussion helpful"* (1%).

(7) I prefer solving problems on my own: it has a positive association with *"did not share the work out evenly"* (5%) but has a negative association with *"worked well together"* and *"could not solve problem myself"* at 1%, *"were not sure had the correct answer"* and *"needed help from other members"* at 5%.

(8) We worked well together as a group: it has a positive association with *"could not solve problem myself"* (1%) and *"needed help from other members"* (5%) but has a negative association with *"did not share the work out evenly"* (1%).

(11) At the end, we were not sure we had the correct answer: it has a positive asssociation with *"could not solve problem myself"* (1%).

(12) I could not have solved the peoblem by myself: it has a positive association with *"needed help from other members"* (1%).

New Unit 8

(1) The problem was enjoyable: it has a positive association with "*worked well together*" (5%) but has a negative association with "*learned nothing*" and "*prefer solving problem myself*" at 5%.

(2) The problem was difficult: it has a positive association with "*worked well together*" (5%) but has a negative association with "*had enough previous knowledge*" (1%).

(3) I found that solving this problem was satisfying: it has a positive association with "*needed help from other members*" (5%).

(5) I learned nothing from the problem: it has a negative association with "*had enough previous knowledge*" (5%).

(7) I prefer solving problems on my own: it has a positive association with "*did not share the work out evenly*" (1%) but has a negative association with "*could not solve problem myself*" (1%), "*worked well together*", "*group discussion helpful*" and "*needed help from other members*" at 5%.

(8) We worked well together as a group: it has a positive association with "*group discussion helpful*" (1%) but has a negative association with "*did not share the work out evenly*" (5%).

(10) I found the group discussion helpful: it has a negative association with "*were not sure had the correct answer*" (5%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

Unit 9

(1) The problem was enjoyable: it has a positive association with "*satisfying*" (1%) and "*had enough previous knowledge*" (5%) but has a negative association with "*were not sure had the correct answer*" (5%) and "*needed help from other members*" (1%).

(2) The problem was difficult: it has a positive association with "*new problem*", "*group discussion helpful*" and "*could not solve problem myself*" at 1% but has a negative association with "*had enough previous knowledge*" (5%).

(3) I found that solving this problem was satisfying: it has a negative association with "*learned nothing*" (5%).

(4) The problem was completely new to me: it has a positive association with "*group discussion helpful*" (1%) and "*were not sure had the correct answer*" (5%) but has a negative association with "*had enough previous knowledge*" (1%).

(5) I learned nothing from the problem: it has a negative association with "*prefer solving problem myself*" (5%).

(6) I had enough previous knowledge to solve the problem: it has a positive association with "*prefer solving problem myself*" (5%) but has a negative association with "*group discussion helpful*" and "*could not solve problem myself*" (5%).

(7) I prefer solving problems on my own: it has a positive association with "*did not share the work out evenly*" (5%) but has a negative association with "*could not solve problem myself*" (1%) and "*needed help from other members*" (5%).

(8) We worked well together as a group: it has a positive association with "*group discussion helpful*" (1%) but has a negative association with "*did not share the work out evenly*" (1%) .

(9) We did not share the work out evenly in our group: it has a negative association with "*group discussion helpful*", "*needed help from other members*" at 1%and "*could not solve problem myself*" (5%).

(11) At the end, we were not sure we had the correct answer: it has a positive asssociation with "*needed help from other members*" (1%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

New Unit 9

(1) The problem was enjoyable: it has a positive association with "*satisfying*" (1%) and "*worked well together*", "*group discussion helpful*" at 5% but a negative association with "*learned nothing*" (5%).

(2) The problem was difficult: a negative association with "*had enough previous knowledge*" (1%).

(3) I found that solving this problem was satisfying: it has a positive association with "*worked well together*" (1%) and "*had enough previous knowledge*" (5%) but has a negative association with "*learned nothing*" (5%).

(5) I learned nothing from the problem: it has a negative association with "*had enough previous knowledge*" and "*group discussion helpful*" at 5%.

(6) I had enough previous knowledge to solve the problem: it has a negative association with "*were not sure had the correct answer*" (5%).

(7) I prefer solving problems on my own: it has a positive association with "*did not share the work out evenly*" (1%).

(8) We worked well together as a group: a positive association with "*group discussion helpful*" (1%).

(9) We did not share the work out evenly in our group: it has a negative association with "*group discussion helpful*" (5%).

(10) I found the group discussion helpful: it has a negative association with "*were not sure had the correct answer*" (5%).

(11) At the end, we were not sure we had the correct answer: it has a positive asssociation with "*could not solve problem myself*" and "*needed help from other members*" at 1%.

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

Unit 10

(1) The problem was enjoyable: it has a positive association with "*satisfying*", "*had enough previous knowledge*", "*worked well together*" and "*group discussion helpful*" at 1% but has a negative association with "*learned nothing*", "*were not sure had the correct answer*" at 1%, "*difficult*", "*did not share the work out evenly*" and "*could not solve problem myself*" at 5%.

(2) he problem was difficult: it has a positive association with "*new problem*", "*were not sure had the correct answer*", "*could not solve problem myself*" and "*needed help from other members*" at 1% but has a negative association with "*worked well together*" (5%).

(3) I found that solving this problem was satisfying: it has a positive association with "*had enough previous knowledge*" and "*worked well together*" at 1% but has a negative association with "*did not share the work out evenly*" and "*were not sure had the correct answer*" (5%).

(4) The problem was completely new to me: it has a negative association with "*did not share the work out evenly*" " (5%).

(5) I learned nothing from the problem: it has a positive association with "*were not sure had the correct answer*" (1%) but has a negative association with "*had enough previous knowledge*" (5%).

(6) I had enough previous knowledge to solve the problem: it has a positive association with "*worked well together*" (1%) but has a negative association with "*were not sure had the correct answer*" (5%).

(8) We worked well together as a group: it has a positive association with "*group discussion helpful*" (1%) and but has a negative association with "*did not share the work out evenly*", "*were not sure had the correct answer*" and "*could not solve problem myself*" at 1%.

(9) We did not share the work out evenly in our group: it has a negative association with "*group discussion helpful*" (5%).

(11) At the end, we were not sure we had the correct answer: it has a positive asssociation with "*could not solve problem myself*" (1%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

Unit 12

(2) The problem was difficult: it has a positive association with "*new problem*" and "*could not solve problem myself*" at 5%, "*were not sure had the correct answer*" (1%).

(4) The problem was completely new to me: it has a positive association with "*could not solve problem myself*" (1%) but has a negative association with "*had enough previous knowledge*" (1%), "*prefer solving probelm myself*" and "*group discussion helpful*" at 5%.

(5) I learned nothing from the problem: it has a positive association with "*could not solve problem myself*" (5%)

(6) I had enough previous knowledge to solve the problem: it has a positive association with "*prefer solving probelm myself*" (1%) and "*group discussion helpful*" (5%) but has a negative association with "*worked well together*", "*were not sure had the correct answer*" and "*could not solve problem myself*" at 5%.

(7) I prefer solving problems on my own: it has a positive association with "*did not share the work out evenly*" (5%) but has a negative association with "*worked well together*", "*needed help from other members*" at 1%, "*could not solve problem myself*" (5%).

(8) We worked well together as a group: it has a negative association with "*did not share the work out evenly*" (1%)

(10) I found the group discussion helpful: it has a positive association with "*needed help from other members*" (5%) but has a negative association with "*could not solve problem myself*" (5%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (5%).

Unit 13

(1) The problem was enjoyable: it has a positive association with "*satisfying*"(1%)

(2) The problem was difficult: it has a positive association with "*needed help from other members*" (1%), "*new problem*", "*were not sure had the correct answer*" and "*could not solve problem myself*" at 5% but has a negative association with "*had enough previous knowledge*" and "*did not share the work out evenly*" at 5%.

(4) The problem was completely new to me: it has a positive association with "*were not sure had the correct answer*", "*could not solve problem myself*" and "*needed help from other members*" at 1% but has a negative association with "*had enough previous knowledge*" and "*prefer solving probelm myself*" at 5%.

(5) I learned nothing from the problem: it has a positive association with "*were not sure had the correct answer*" (1%) but has a negative association with "*had enough previous knowledge*" (5%).

(6) I had enough previous knowledge to solve the problem: it has a negative association with "*were not sure had the correct answer*" (5%).

(7) I prefer solving problems on my own: it has a negative association with "*worked well together*" and "*needed help from other members*" at 1%, "*could not solve problem myself*" (5%).

(8) We worked well together as a group: it has a positive association with "*group discussion helpful*" (1%), "*could not solve problem myself*" and "*needed help from other members*" at 5%.

(10) I found the group discussion helpful: it has a positive association with "*needed help from other members*" (1%) and "*could not solve problem myself*" (5%).

(11) At the end, we were not sure we had the correct answer: it has a positive asssociation with "*could not solve problem myself*" and "*needed help from other members*" at 1%.

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

Unit 14

(1) The problem was enjoyable: it has a positive association with "*satisfying*" (1%) but has a negative association with "*learned nothing*" and "*did not share the work out evenly*" at 5%.

(2) The problem was difficult: it has a positive association with "*were not sure had the correct answer*" (1%).

(3) I found that solving this problem was satisfying: it has a positive association with "*had enough previous knowledge*" (5%) but has a negative association with "*learned nothing*" (1%).

(4) The problem was completely new to me: it has a positive association with "*group discussion helpful*", "*could not solve problem myself*" and "*needed help from other members*" at 5%.

(5) I learned nothing from the problem: it has a positive association with "*did not share the work out evenly*" (1%) but has a negative association with "*had enough previous knowledge*" and "*group discussion helpful*" at 1%.

(6) I had enough previous knowledge to solve the problem: it has a negative association with "*did not share the work out evenly*" (1%) and "*were not sure had the correct answer*" (5%).

(7) I prefer solving problems on my own: it has a positive association with "*did not share the work out evenly*" (1%) but has a negative association with "*worked well together*" and ""*group discussion helpful*" at 1%.

(8) We worked well together as a group: it has a positive association with "*group discussion helpful*" (1%) but has a negative association with "*did not share the work out evenly*" (1%).

(10) I found the group discussion helpful: it has a positive association with "*needed help from other members*" (5%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

Unit 15

(1) The problem was enjoyable: it has a positive association with "*satisfying*" (1%) and "*had enough previous knowledge*" (5%) but has a negative association with "*new problem*" (1%).

(2) The problem was difficult: it has a positive association with "*could not solve problem myself*" (1%) and "*needed help from other members*" (5%) but has a negative assocation with "*were not sure had the correct answer*" (1%).

(3) I found that solving this problem was satisfying: it has a negative association with "*new problem*", (1%), "*learned nothing*" and "*needed help from other members*" at 5%.

(4) The problem was completely new to me: it has a positive association with "*needed help from other members*" (5%).

(5) I learned nothing from the problem: it has a positive association with "*prefer solving problem myself*" (1%).

(7) I prefer solving problems on my own: it has a negative association with "*worked well together*" (1%).

(8) We worked well together as a group: it has a positive association with "*group discussion helpful*" (1%).

(11) At the end, we were not sure we had the correct answer: it has a negative asssociation with "*needed help from other members*" (5%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

Unit 16

(1) The problem was enjoyable: it has a positive association with "*satisfying*", "*worked well together*" at 1%, "*had enough previous knowledge*", ""*group discussion helpful*" and "*needed help from other members*" at 5% but has a negative association with "*learned nothing*" (1%).

(2) The problem was difficult: it has a positive association with "*were not sure had the correct answer*" and "*needed help from other members*" at 1%, "*new problem*" (5%) but has a negative association with "*had enough previous knowledge*" (5%).

(3) I found that solving this problem was satisfying: it has a negative association with "*learned nothing*" (1%).

(4) The problem was completely new to me: it has a positive association with "*could not solve problem myself*" and "*needed help from other members*" at 1% but has a negative association with "*had enough previous knowledge*" (5%).

(6) I had enough previous knowledge to solve the problem: it has a positive association with "*worked well together*" (1%) and "*group discussion helpful*" (5%) but has a negative association with "*could not solve problem myself*" (5%).

(7) I prefer solving problems on my own: it has a negative association with "*could not solve problem myself*" and "*needed help from other members*" at 1%.

(8) We worked well together as a group: it has a positive association with "*group discussion helpful*" (1%) and "*needed help from other members*" (5%) but has a negative association with "*did not share the work out evenly*" and "*were not sure had the correct answer*" at 1%.

(9) We did not share the work out evenly in our group: it has a negative association with "*needed help from other members*" (5%).

(10) I found the group discussion helpful: it has a positive association with "*needed help from other members*" (1%).

(12) I could not have solved the peoblem by myself: it has a positive association with "*needed help from other members*" (1%).

Unit 18

(1) The problem was enjoyable: it has a positive association with "*satisfying*" (1%)

(2) The problem was difficult: it has a negative association with "*had enough previous knowledge*", "*prefer solving problem myself*" and "*needed help from other members*" at 5%.

(3) I found that solving this problem was satisfying: it has a negative association with "*were not sure had the correct answer*" and "*could not solve problem myself*" at 5%.

(7) I prefer solving problems on my own: it has a positive association with "*needed help from other members*" (5%).

(8) We worked well together as a group: it has a positive association with "*could not solve problem myself*" (1%) and "*group discussion helpful*" (5%) but has a negative association with "*did not share the work out evenly*" (1%).

(9) We did not share the work out evenly in our group: it has a negative association with "*group discussion helpful*" (5%)

Appendix J

Chi-Squared Anlysis Results

Chi-Squared Analysis Results

Unit1 to New Unit1			
	Chi-Squared	df	significant
Q1	5.3	1	*
Q2	2.1	1	
Q3	0.1	1	
Q4	0.9	1	
Q5	2.0	3	
Q6	1.4	2	
Q7	3.0	3	
Q8	11.2	1	**
Q9	2.7	1	
Q10	0.3	1	
Q11	2.1	3	
Q12	3.0	3	
Q13	1.3	3	

Unit2 Scotish to Taiwan			
	Chi-Squared	df	significant
Q1	0.0	1	
Q2	24.5	2	**
Q3	6.0	1	*
Q4	14.6	3	**
Q5	0.6	1	
Q6	8.7	2	*
Q7	0.4	2	
Q8	2.7	1	
Q9	4.4	3	
Q10	0.0	1	
Q11	10.3	3	*
Q12	3.9	3	
Q13	13.3	3	**

Unit 5 to New Unit 5			
	Chi-Squared	df	significant
Q1	16.7	1	**
Q2	1.3	1	
Q3	9.5	1	**
Q4	7.7	1	**
Q5	0.5	1	
Q6	0.4	1	
Q7	0.9	1	
Q8	2.9	1	
Q9	6.2	2	*
Q10	3.9	1	*
Q11	9.2	1	**
Q12	0.4	1	
Q13	0.5	1	

Unit 8 to New Unit 8			
	Chi-Squared	df	significant
Q1	7.3	1	**
Q2	1.1	1	
Q3	2.4	2	
Q4	4.2	1	*
Q5	1.1	3	
Q6	4.0	2	
Q7	1.2	1	
Q8	0.0	1	
Q9	0.2	1	
Q10	2.6	1	
Q11	0.6	2	
Q12	0.4	3	
Q13	0.5	2	

Unit 9 to New Unit 9			
	Chi-Squared	df	significant
Q1	15.4	2	**
Q2	0.2	1	
Q3	5.9	2	*
Q4	2.1	1	
Q5	0.2	1	
Q6	1.1	1	
Q7	1.5	1	
Q8	0.1	1	
Q9	2.0	1	
Q10	1.1	1	
Q11	1.1	1	
Q12	0.0	1	
Q13	0.1	1	

df	0.05	0.01
1	3.84	6.63
2	5.99	9.21
3	7.81	11.34
4	7.49	13.28

Appendix K

Tape Transcripts

B: Take coal first. (Slightly)
A: So part 1.... C plus O to CH_2. Because CO_2 for CH_2, no, wouldn't it? H_2 wouldn't it? No, wouldn't be such CO_2.
B: No, I am burning a fuel over O.
A: That's only for hydrocarbon,.....just CO_2.
B: CO_2?
B: No, wait......
C: Besides, what hydrogen coming that?
A: I know, if you can't get through.....Part 2, another 2, so C eleven is still.......
C: That will give you things.
A: H 24, 24 plus O_2 gives you H_2O and CO_2.
B: Wait, how do you do that?
C: That's because you......
A: 24 that's 12 hydrogens, so that's 12, 22..
B: Did the dot mark special........
A: It 36 oxygens here.
B: Let me see, let me see....
A: It's eighteen.
C: eighteen?
A: Yeh, let us do part B, gas c.
A: Give 3 over 2 which is ....
C: CO_2 plus H_2O...., that's twenty.
(B made noise....)
A: That's 5 over 2. (C: Calm down here, calm down)
How could the formula .... that's fine. So C is 12.
A: Ok, for the first one, C is 12, ...the formula masses of the fuels is .., no, here part 2
B: Calculate formula masses of coal?
A: Because twelve times one, equals 12, now ok so the next one is oil.
B: You need a calculator?
C: No, but wait, twelve times 11 is 122 plus twenty-four is hundred forty six.
C: Hundred forty six?
A: We don't, we don't, ...,twenty four that's six you write...
C: No, we have to do it like this, we have to be the best. was that twelve times 11 plus..?
A: Twenty-four times one, equals 146 grams. Ok, gas, CH_4, that would be twelve sixteen.......
(Calculation,...reading...)
A: Assume that the energy released is related to ....
B: Why don't you stop that what are you doing? because the energy is from....
C: I need the calculation of it.
B: We doesn't need a scrap piece of paper to do the calculations, ... what are you doing?
C: We are reading.
A: Part B,...
C: That's oks, oil, oil, you just put down oil, because ...., each one by thousand,.......one kilo zeros equals....... one thousand grams, this has got the most grams so obviously it is going to be oil.
A: Yeh, oil will give the most as it has the most products.......that's based on the number of molecules.
C: Oil is the most to that, how many molecules ... has to be right. Weigh molecule.

C: Six point O2…
A: Ok, oil is … oil will… oil gives it the greatest of energy.
B: Per kilogram, write per kilogram, is it?
C: Per kilogram.
A: We should look further working.
C: Yeh, not up here.
A: Ok, back to them. Oil gives…., as oil it gives the more………. guess I think so.
C: You are told to assume that…..(reading)
A: Have you read it yet, part 1, what do you think?
B: I would say it was …………or why? Just go up?
C: Is hydrogen bonding …..,giving the meaning?
A: Yeh, assume, as probably it might a hydrocarbon such as the structure for the bonding.
C: Hydrocarbon molecular bonding ………..begin to that…
A: I remembered………………. my sister's exercise, there was a question, it wasn't sure a good answer that the burning fuel aren't based on the number of molecules, is based on structure and certain hidden factors, so must be the same for this.
C: Just write it down.
A: It's mostly grams,…….yes, put down
A: It isn't, as…., it's a fair assumption. Taking into account other factors, structural bonding and then this is finished. Alright there is two sheets.
C: We are on the second sheet, aren't we?
A: No, because of…..bonding structure and intermolecular forces.
C: But that's just bonding, intermolecular forces into bonding, we'll just put it down.
A: Just put it down. Ok, that's us, I'll just tell them.
(Teacher came and checked the answer:
I am not sure about you got the same answer as oil, everything else you've got is right,…………if you could give a little……….how you got the answer, that will helpful.)
(Pupils checked the answers)
A:……..write down about the answer, oil isn't the answer.
C: It's because contains most carbon and hydrogen.
C: Atoms, molecular, therefore more energy gives out, each atom burns.
A: Oil is not the answer….
A: Then you can pick one,…………, it's because smaller molecular seems give the idea, so you got more to burn, more products.
C: Gas can't be a possible answer?
B: …isn't the coal over?
A:No, I did remember that a system would happen…………….
C: You read a book? You don't take that?
C:….that's because got most number of …., (B: molecules and atoms, pair of molecules…) and therefore more energy released…..
C: Take into account, gathering the right... coal as one, gathering the gas as one...
C: Gas can't be a possibility, because gas ……..and then you burn gas…
A: …it gives a quick about …?….and soluble and gas, then the solvent gives….
A: I would say that, because the number of molecules.. must be formed, there are more moles formed
A: There are moles of the products, therefore more energy released…..
B: There are more moles in the balanced equation.
A: I think it is gas.

B: The heat pack produces its heat by means of a chemical reaction. Look very very carefully. How could us discuss?

C: They all fixed together (.....), they all right.

A: We do.

B: Mars, told us what we can pave(.....) first?

B: ...where the heat energy comes from? Why it gives the iron powder and carbon powder together?

C: How does it work?

B: ....You mean mix together?

C: Every iron reacts together?

B: No, would it is paper .... do that?

A: See you go that, I think that's.............................. might come to reaction, could you seize....... starting electricity? (B: a hand?) What charge inside of it and transfer to the pack?

B: Just write about when you.................together from a chemical reaction.

B: What's the fabric for? What that's for?

C: That's an....................that heat the end........

B: How it works?

A:......give the wee rub of it.

C: did you understand that what?

B: No

A: Would it do, cold?

B:.............for to make through including a reacting, so the paper do it.

(Teacher:.............. You are looking for something producing the heat energy, aren't you? You are looking for the chemical reaction somewhere and that should be componesed(?). So you got iron, carbon, salt and damp this. Ok, the clue is the main material, these one must be involved in the main reaction somewhere. Because otherwise we could be ...., so has to be iron reacting with something. Ok, go on talking about that.............)

C: Write down the.........damp is ....iron?

B: Something has bonded to be........, maybe with..............or.................

A: If we go up, then we expected that ....start the reaction.

(Teacher: But that's done, that's already.)

A: Shaked that all, mixed that all together.

(T: If you shaked and rubbed together, that will encourage mixing, you know, mixing bring the reactants together, so that's helpful for the reaction, but it doesn't the reaction..........)

A: How the reaction happen?

(T: You got to work out............you know the iron reacting with something, the main interesting things is that ....whatever the other reactant is , it is one of them..........)

A: See, genius, genius...... the air gas come in........................

(T: *You also need to think of the directions, here is a hint,....these four parts, just think of these four parts*)

A: Yeh, right, so the air gas ....and just about a chemical reaction.

........you can speed up the reaction.

C: Is the reactant like a catalyst?

B: That's I said, heat is a catalyst, that's why ....

(T: *When you open the airtight bag, the air gets in and starts the reaction, when you shake it, it mixes the reactant together and the moist cellulose acts as a conductor to draw the heat away from the* *core.)*

B: Why is iron powder used as the main material?

A: Because we can see it ....

B: Shouldn't iron ....

C: Suggest any other powdered metal that might be used, giving reasons for your choice. Suppose....

A: Magnesium.

B&C: Why?

A: Just good. Because reacts with oxygen.

C: It burns your hand.

A: Reacting with oxygen.

C: What is iron's symbol?

B: Fe.

A: ......you can use manganese(Mn) product or...

B: Is cheaper?

C:...hold on, why is iron the main material?

B: Because it's cheap, cheap....

C: Because it is cheap and.......easy to use.

A: As it is a good reactant with oxygen.

(Noise)

A: You would like me to speak.....right, where to start the reaction....that's finished, and you used the very fine carbon powder as it's ....

B: Why it is salt?

A: I don't know, ...

B: It is not a wrong answer, you see.

A: It is a main reactant.

(Noise....)

C: All right, go for another element.........

A: Right, next.....................Manganese could be, because it has near similar property.

C: Manganese is also another metal...

A: That has similar chemical properties to iron therefore,...It can be used as a substitute for iron, symbol is Fe.