# A PILOT STUDY OF COMMONLY HELD MISCONCEPTIONS IN SECONDARY SCHOOL GENETICS

by

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*A B S T R A C T*

*This pilot study was aimed at investigating with the aid of a two-tier multiple choice questionnaire, the misconceptions held by pupils in standards 8 and 10 as well as first year Biology students in the area of senior secondary school genetics.*

*It was found that certain of the children's preconceived ideas were altered by tuition while others were unaffected by either age or tuition and consequently warranted the name misconceptions. Four misconceptions were identified in this study and these were seen to be at the root of the difficulties experienced in genetics. They involved plants being seen to be unable to reproduce sexually, an inability to relate meiosis to genetics, a tendency to cling to the Punnett square algorithm when solving genetics problems despite a lack of understanding of the underlying processes and a failure to see the role of chance in genetics.*

*These misconceptions were seen to have arisen because of certain preconceived ideas which hamper the formation of a suitable conceptual framework. The adoption of suitable teaching strategies appears to be the most likely method of rectifying the problem. However, before this can be regarded as conclusive, further research into the concept development of specific aspects such as sexual reproduction, needs to be done. Studies to investigate the most suitable teaching strategy should also be carried out as well as an investigation into the structure of the curriculum.*

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# CHAPTER 1

## INTRODUCTION

Genetics has proved to be an area of perceived difficulty for both the teacher and the pupil (Johnstone and Mahmoud, 1980; Finley et al., 1982; Longden, 1982; Radford and Bird-Stewart, 1982; Stewart, 1982) and yet it continues to be included in British, American, Australian and South African Biology courses. The importance of genetics can be summarised as "its ubiquity in high school biology courses; its importance in understanding modern evolutionary theory and its potential for social import." (Stewart and Dale, 1982, p. 60).

In Britain prior to 1960, genetics in the form of heredity and evolution, was not included below A level (candidates usually 18 years old) except for non-examined courses for younger, less able pupils (Bibby, 1950, and Tyrer, 1954, in Deadman and Kelly 1978). Thereafter the value of these topics was noted and they became "central concepts in biological understanding" (Deadman and Kelly, 1978, p 7). As such it was argued that all pupils should be exposed to genetics before they left school at the age of sixteen. Consequently, the subject was introduced mainly at O-level (Deadman and Kelly, 1978).

In South Africa genetics is included in the senior secondary course of the National core syllabus. In the Cape Education Department it is dealt with in the standard 9 (year 11) syllabus although chromosomes, genes and DNA are mentioned in the standard 7 (year 9) and 8 (year 10)

Biology courses.

Collins and Stewart (1989) attribute the difficulty experienced with genetics to the complex nature of the content knowledge and the fact that it is tested using problem solving exercises which in turn are a complex task. A variety of other reasons have been suggested by other researchers (discussed in chapter 2). Longden (1982) went a step further by characterising the problems as either teacher or pupil related. Teacher related problems include such factors as competence with and perceived relevance of genetics. These factors obviously do play a part but the researcher feels that it would be more useful to concentrate on the pupil and the problems he or she has with the subject.

These problems are thought to exist because of the preconceived ideas held by the pupils rather than a lack of intrinsic cognitive ability as suggested by researchers with a Piagetian outlook. Constructivists are of the opinion that every child has a conceptual framework and that this influences what he or she learns. Although this framework is unique to each child, certain preconceptions are common. These could also be so long-standing and dominant that they are not easily changed. When these ideas are at odds with the work taught in school, a problem arises as these ideas, termed misconceptions, hinder further learning.

In the field of genetics a number of misconceptions have been isolated. The aim of this study is to investigate these in a general way as well as specifically focussing on the misconceptions responsible for the pupils' inability to link cell division, fertilisation and genetics together. This will be done using three groups of subjects. The standard 8 group will mainly represent the preconceived ideas gained in everyday life. The standard 10 group will represent the misconceptions that are sufficiently dominant to remain a year after a course in genetics. The first year students will represent the misconceptions that have remained soon after the completion of a comparatively intensive course in genetics.

The test instrument used will be a two-tier multiple choice questionnaire (Treagust, 1985, in Haslam, 1987; Treagust, 1988). This was chosen for a number of reasons. Firstly, it is quick and easy to use so time utilisation is not a problem. The questionnaire can be completed in one period ($\pm$ 35 minutes). It will be drawn up using actual responses generated by a free response questionnaire, so the misconceptions being investigated have already been found to exist in the classroom. Finally, the fact that it is composed of two parts means that even if the pupils have rote learnt all the necessary facts, they are unlikely to be able to chose the correct reason unless they do understand the underlying processes. In this way it is to be hoped that misconceptions will be accurately identified.

The identification will be done using computer analysis after which possible reasons for the existence of the various misconceptions will be suggested. Finally, ways of alleviating the problem will be discussed.

# CHAPTER 2

## CONCEPTUALISATION OF THE PROBLEM

The ideas pupils bring with them to the classroom appear to be central to the problems experienced in genetics teaching (Cho et al., 1985). What these ideas are and how they influence the new information presented during tuition, is vital information which is needed to solve these problems.

Not all researchers share this view. Piagetian theorists such as Shayer (1974) and Gaskell (1973) (in Simpson and Arnold, 1982) believe that the pupils have not yet attained a high enough level of formal thought to cope with the concepts involved. Formal operational thought as described by Inhelder and Piaget (in Walker, Mertens and Hendrix, 1979) is characterised by the ability to perform three types of cognitive reasoning namely combinatorial logic, propositional logic and hypothetico-deductive reasoning. They believed that this type of reasoning develops from concrete operational thought between the ages of 11 and 15 although recent studies have shown that development could extend much later than 15 years (Walker et al., 1979) even to the extent that college students have not reached that level of thinking yet (Haley and Good in Walker et al., 1979).

A study by Walker et al. (1979) showed that there was a significant relationship between performing Piagetian tasks of propositional logic and combinatorial logic and the pupil's ability to solve genetic problems. However, this was not the case for hypothetico-deductive reasoning. The various criticisms of Piaget's work and the lack of concrete evidence leads one to consider other factors to explain the problems faced in genetics.

Ausubel, a cognitive psychologist with views similar to the constructivist views of Piaget, based his theory of learning on the premise that what the learner already knows has the greatest influence on what is learnt. Meaningful learning is seen to occur when "new knowledge <u>interacts</u> with existing relevant concepts and is <u>assimilated</u> into these concepts, thus altering the form of both the anchoring concept and the new knowledge assimilated" (Novak, 1978, p. 5). During rote learning on the other hand, no interaction takes place. Older children can therefore solve more complex problems because they have built up more elaborate conceptual frameworks than younger children, not because they have developed further cognitively. As far as genetics is concerned, this view is supported by Novak (1978, in Stewart & Dale, 1981) who believes that it is a lack of appropriate cognitive preparation rather than a lack of intrinsic ability to think at a formal level that is responsible for the pupil's inability to solve genetics problems.

The constructivist tradition of educational psychology appears to present the most feasible explanation of how children learn. There are similarities to Ausubel's work but the emphasis is on the cognitive structure of the individual. Kelly (1955) (in Osborne and Wittrock, 1985, p 62) stated that each person builds representational models which help him or her cope with the world. Claxton (1984) (in Osborne and Wittrock, 1985) built on Kelly's theory. He believed that initially a child has a very narrow view of the world but this expands with experience. The child uses mini-theories to cope with certain circumstances and as the circumstances change so the mini-theories are modified. The mini-theories can be seen as an unconscious way to explain things and as such could be equivalent to preconceptions (Ausubel (1968) in Driver and Easley, 1978), alternative frameworks (Driver and Easley, 1978) and childrens' science (Gilbert, Osborne and Fensham, 1982).

The views of Kelly and Claxton led to the generative learning model (Osborne and Wittrock, 1985) which is based on the premise that people have to actively generate links between new information and information gained from previous experience. It is felt that this view is very close to reality due to the fact that the model stresses the learner and the effort required on his or her part to acquire new information. The model can be summarised as follows:

When new information is presented to a pupil, his previous ideas focus his attention on a particular part. The new information is merely a collection of words until the pupil links the words to a particular picture in his mind. The picture that is formed results from linking the words to a prior experience. By forming these links, the pupil is attempting to explain the new information to his personal satisfaction. Once this has been done, the explanation is tested against existing knowledge and, if it fits in with these existing issues, the new information can be stored (subsumed). This process may alter the stored information in some way i.e. the pupil's preconceptions or mini-theories may be modified when new but related information is accepted and incorporated into the cognitive structure.

Misconceptions arise when the wrong links are made. This could jeopardise further learning in that future work may not fit into the child's cognitive structure at all. Children will rather ignore inconsistent facts than subject their cognitive frameworks to major restructuring which they find threatening. Furthermore, if only a few links are generated to tie a particular concept into the child's cognitive framework that concept will be easily forgotten.

Driver and Bell (1986) take a broader view of the child as a constructer of information, not paying as much attention to the actual links generated. They saw classroom science as seldom being meaningful to the child and consequently being difficult to apply. The child pays attention to the parts which are interesting and relevant to him and ignores the rest which is usually the part the teacher wants him to learn. This leads to a compartmentalisation of the school science and the everyday science which was termed a 'two-world perspective' by Osborne and Wittrock (1985). This is more likely to occur if the subject is abstract, such as in the case of genetics.

Kargbo, Hobbs and Erickson (1980) found that

> "children of six to 13 years have already formed their own theories or 'alternative frameworks' (Driver and Easley, 1978) to explain the various forms of phenotypic traits which are exhibited by the various living organisms around them."
>
> (Kargbo et al., 1980, p. 145)

These frameworks were categorised as environmental ('It is the mother who gives the pups their colour because she cares for them'), somatic ('the pups will be black if the mother has black teats'), naturalistic ('the man is tall, the boy will be a man so he will be tall') or genetic ('some will be black like the mother and others will be like the father'). The first three were characteristic of children under ten years of age so should not influence the results of this study, while the last was seen to be characteristic of children over ten (Kargbo et al., 1980) so could be influential to the results.

Deadman and Kelly (1978) on the otherhand found that some preconceived ideas were independent of age and were sufficiently dominant to remain with the pupil regardless of what he was taught to the contrary at school. Many other theorists have similar views concerning the ideas that children hold. Driver and Erickson (1983) list various terms for these ideas (alternative frameworks and children's science have already been mentioned) and coin the term conceptual frameworks. They believe that some types of frameworks are universal and stable while others are idiosyncratic and fluid. The problem arises when a stable framework interferes with the learning of school science because it resists change.

It is these steadfast preconceived ideas (termed misconceptions as they are contrary to what is taught) that cause pupils problems when they are learning genetics. Researchers have isolated a number of misconceptions which have caused problems in various areas of genetics.

Reproduction is one such area. Okeke and Wood-Robinson (1980) found, for instance, that plants were not thought to reproduce sexually. As most genetics courses start with Mendel's work with pea plants, it is not surprising that pupils have difficulty relating sexual reproduction to genetics. Furthermore, Clough and Wood-Robinson (1985) found that pupils believe that one or other of the parents makes a more significant genetic contribution to their offspring than the other. This, together with the inability to grasp the concept of chance (Deadman and Kelly, 1978; Kargbo et al., 1980; Hackling and Treagust, 1984), could result in problems when dealing with monohybrid and dihybrid crosses and sex determination.

In addition, various researchers (Stewart and Dale, 1981; Longden, 1982; Stewart, 1982; Moll and Allen, 1987) have found that pupils also have difficulty linking the movement of chromosomes during meiosis and the formation of gametes. From these findings it would appear that some of the problems children have with genetics could stem from an inability to incorporate cell division, fertilisation and genetics into one conceptual framework. This inability could be due to the pupils being unable to relate chromosomal separation to DNA replication, a pair of alleles to trait expression and the movement of chromosomes to trait transmission (Cho et al., 1985).

These three misconceptions could also cause specific problems. The first could result in a misconception regarding the term 'chromatid' (Longden, 1982), the second in misconceptions when dealing with the terms homozygous/heterozygous and dominant/recessive and the third in misconceptions which prevent a full understanding of the processes involved in mono- and dihybrid crosses (Stewart, 1982). Related to the latter are the misconceptions associated with the mathematical aspect of solving genetics problems (Kargbo et al., 1980; Longden, 1982; Radford & Bird-Stewart, 1982). These arise not only from an inability to link genetics and meiosis, but also from the inability to acknowledge the role of chance in the process as previously mentioned. Longden (1982) attributed the latter problem to frequent and rote use of Punnett squares and Hackling and Treagust (1984) suggested that the emphasis on phenotypic ratios led to an inability to comprehend the 'law of large numbers'.

Other misconceptions have been connected to the fact that genetics is an abstract subject bound up in a vocabulary all of its own. Stewart and Dale (1981) found that pupils did not understand certain concepts such as gene and allele, and as these are central to the issue, it is not surprising that they were also unable to describe how concepts such as gene-allele, allele-zygote etc. were related (Stewart, 1982).

The 'Bur' model of a concept (Schaefer, 1979) is suitable to explain this problem. This model sees a concept as made up of a logic core and a name. This means that the name of the concept has certain facts associated with it for example 'mammal' is characterised by hair, mammary glands, being homeothermic etc. The concept is embedded in a network of associations which enables the person to relate to it. These associations are attached to the hooks of the burr from which the model gets its name. As the concepts presented to the pupils during an introductory genetics course are both new and abstract, the burrs are possibly very small and have very little attached to them. Consequently, it is not surprising that pupils experience difficulty with the terminology.

In summary: pupils experience difficulty with genetics because of misconceptions, content-related problems and conceptual difficulties. Various reasons for these problems have been suggested, the most significant being an inability to form a suitable conceptual framework. This in turn could be caused by an inability to form suitable 'burs' for the various concepts.

# CHAPTER 3

## RESEARCH PROCEDURE

### INTRODUCTION

The identification of students' conceptions is of prime importance to researchers and teachers. However, in the past it has proved a time-consuming and specialised task as it has involved individual student interviews. As an alternative to teachers interviewing their pupils, a paper and pencil multiple choice test represents an effective, time-efficient means of identifying these misconceptions (Treagust, 1988).

The two-tier multiple choice test devised by Treagust in 1985 has the advantage of testing the pupils' understanding of the facts rather than merely their rote recall. Haslam (1987), (Haslam & Treagust, 1987) found that in some instances the pupils are able to supply the correct answer but not the associated reason which shows a lack of understanding of the underlying principles. For this reason, this diagnostic test was used in this study.

The test has the advantage of using responses generated in a pilot study, so it is the pupils' actual misconceptions that are involved, not the researcher's idea of the pupils' possible misconceptions. Once a diagnostic test of this nature has been drawn up for a particular subject such as 'Covalent Bonding and Structure' (Peterson (1986) in Treagust, 1988) and 'What Do You Know About Photosynthesis and

Respiration in Plants' (Haslam, 1987), it can be adapted to suit the particular class by adding or omitting responses where necessary. As this test is easy to use, teachers will be more inclined to use it and once the misconceptions have been identified, the teacher "will be more inclined to remedy the problem by developing alternative teaching approaches" (Haslam, 1987, p. 170) which is ultimately the aim of this type of research. This is an additional reason for choosing to use this test.

**METHOD**

The test used in this study was devised along the lines of those used by Haslam (1987) which are summarised by Treagust (1988) as follows:

DEFINING THE CONTENT

1. Identifying propositional knowledge statements.
2. Developing a concept map.
3. Relating propositional knowledge to the concept map.
4. Validating the content

OBTAINING INFORMATION ABOUT THE MISCONCEPTIONS

5. Examining related literature
6. Conducting unstructured student interviews.
7. Developing multiple choice type questions with free response answers.

DEVELOPING THE TEST INSTRUMENT

8. Developing the two tier diagnostic test
9. Designing a specification grid.
10. Continuing refinements.

As this is an exploratory not a definitive study, these steps were not rigidly adhered to, but used instead as guidelines.

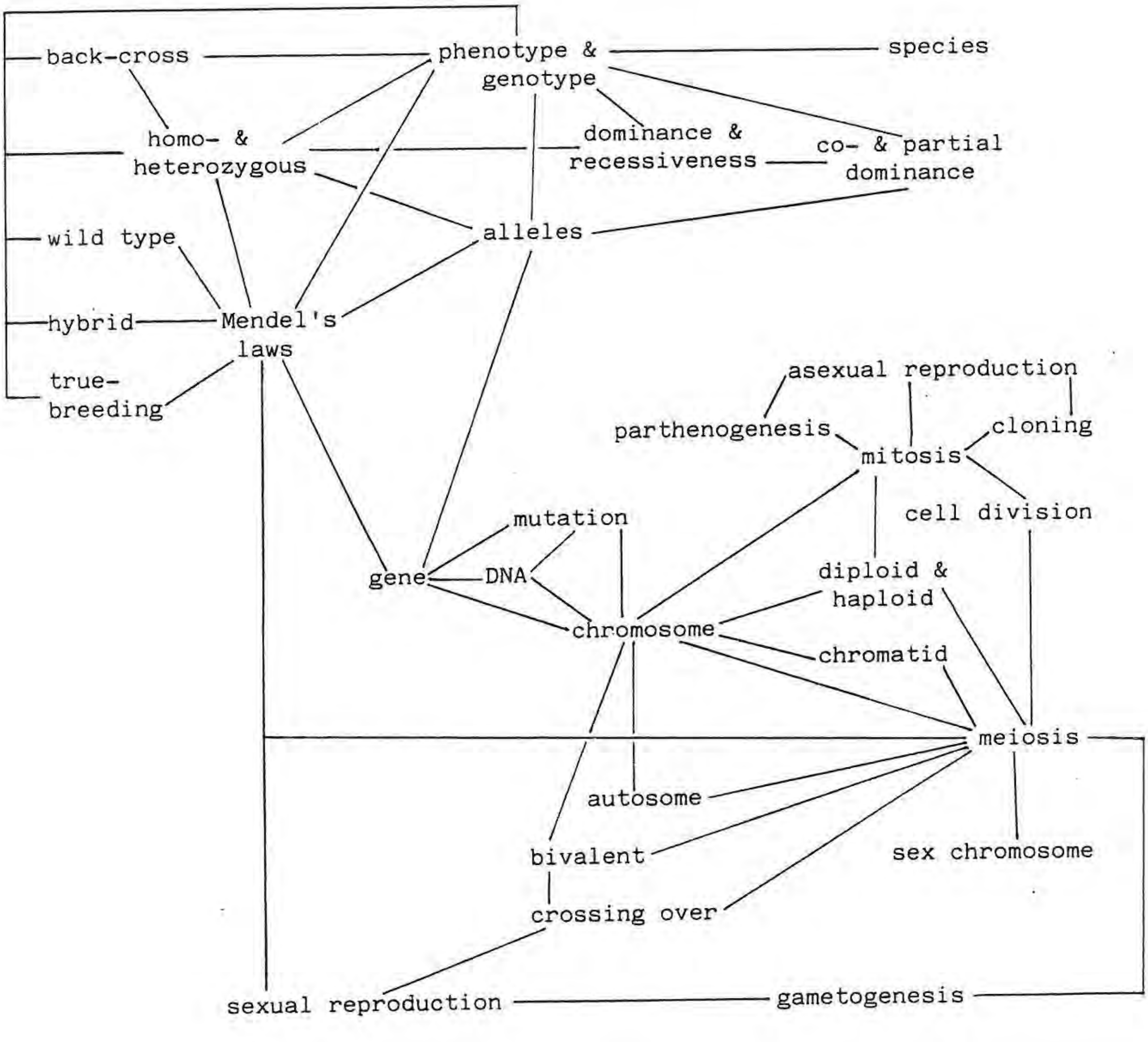
DEFINING THE CONTENT

As this is a pilot study, it was felt that the study should broadly cover the aspects of monohybrid crosses as taught in the standard 9 course and relate these to sexual reproduction (specifically gametogenesis and fertilisation) and meiosis (specifically the movement of chromosomes during the division). A concept map covering these areas is depicted in figure 1. All the concepts in this map are included in the textbooks available for use in schools in the Cape Province. This satisfies steps 3 and 4 as none of the content to be tested is beyond the scope of the pupils.

OBTAINING INFORMATION ABOUT THE MISCONCEPTIONS

Relevant literature was examined and related to the researcher's classroom experience. Having taught genetics for 7 years, it was not deemed necessary to conduct step 6 as the researcher already had a broad perspective of the students' understanding of the topic. Using this knowledge a free response pilot questionnaire (appendix A) consisting of 14 questions some of which were sub-divided into shorter questions covering the same topic, was drawn up. The questions were all open-ended and required a written response from the subject with an explanation for the particular answer given. The final question was a general question asking the subject to list the aspects of genetics he or she found most difficult.

FIGURE 1: Concept map of senior secondary school genetics (adapted from Pearson and Hughes, 1986)



DEVELOPING THE TEST INSTRUMENT

Using the responses generated in the pilot questionnaire, a two-tier multiple choice questionnaire was drawn up (appendix B). The first tier consisted of a multiple choice question with four possible answers. The second tier consisted of four possible reasons for the answer selected in the first tier. To minimize guessing and to encourage honest answers, a space was provided at the end of the question for a different reason. The answers given in the pilot questionnaire were used to generate the options in the first tier and the explanations given were used as the reasons in the second tier.

Certain questions in the pilot questionnaire were generally correctly answered, namely questions 4.2, 6, 10 and 12. These were omitted from the multiple choice questionnaire as they were unlikely to generate any commonly held misconceptions. An additional question was added (question 9.3) to cover the aspect of chance. The questions were arranged so that the first four questions were of a general nature so that they could be administered to the standard eight classes while the following five questions were applicable to the standard 10 (year 12) and first year university groups.

After the draft questionnaire (appendix B) was examined by a number of lecturers and teachers, possible ambiguities arising from the wording of certain questions were corrected and the final test instrument (appendix C) completed.

**SUBJECTS**

As this is a pilot study only a limited number of schools were used for the survey. Six schools and two universities in the Eastern Cape were used in all. The pilot study was carried out using the standard 10 classes in two schools, one a boys' high school and the other a girls' high school. The actual study was carried out using the standards 8 and 10 classes in four co-educational schools and the first year biology classes in two universities.

The subjects were predominantly white and English speaking but as non-racial schools were used, the other race groups were also represented. Furthermore, one of the universities was bilingual. Language should not have influenced the results, however, as the subjects were all *au fait* with the English language as a method of instruction and means of communication.

The pilot questionnaire (appendix A) was administered to 80 pupils (47 male and 33 female) ranging in age from 16 to 18 years of age. The actual study was carried out using three groups of pupils. In this way, misconceptions that exist before formal tuition (standard 8) can be identified as well as ones that have remained or resurfaced a year after tuition (standard 10) and after tertiary tuition (first year university students). A total of 250 subjects completed the questionnaire. The standard 8 questionnaire was administered to 110 pupils (57 male and 53 female) whose average age was in the 15 to 16 years of age range. The longer questionnaire was completed by 88 standard 10 pupils (45 males and 43 females who were in the 17 to 18 year old age range) and 52 first year Zoology, Botany or Biological Science students (28 males and 24 females who were predominantly in the 18 to 21 year old age range).

**ANALYSIS**

The pilot questionnaire was analysed with a view to the drawing up of the multiple choice questionnaire so although answer frequencies were calculated, the emphasis was on finding suitable answer options. The answers obtained in the actual study were coded for computer analysis which was done using the BMDP statistical package. Frequencies and percentages for rows and columns were calculated and the Chi square test of independence carried out.

# CHAPTER 4

## ANALYSIS OF QUESTIONNAIRES

### PILOT QUESTIONNAIRE

The pilot questionnaire (appendix A) was drawn up with the aim of generating possible answers and responses for the subsequent development of a two-tier multiple choice questionnaire to be used in the actual study.

The questions were chosen to cover the following aspects which had been selected as possible problem areas:

1. Sexual reproduction in plants.

2. The genetic contribution of parents during sexual reproduction.

3. The aspect of chance in genetics.

4. The movement of chromosomes during meiosis so linking cell division, fertilisation and genetics.

5. The pupils' opinions regarding areas of perceived difficulty in genetics.

The fourteen questions selected for the pilot questionnaire were worded so that they were in a free response format and an explanation or reason was required for each answer.

Questions 1, 2 and 3 were taken from a survey done by Kargbo, Hobbs and Erickson (1980).

Question 4 was taken from a study done by Clough and Wood-Robinson (1985).

Questions 5, 6 and 7 were based on misconceptions identified by Hackling and Treagust (1984).

Question 8 was based on a similar question in one of the prescribed Biology textbooks (Claassens et al., 1986).

Question 9 was loosely based on questions in Van Rensburg and Roux (1988) and Roos and Van Schalkwyk (1981).

Question 10 was devised apropos the work of Stewart (1982) following that question 11 (based on Van Dyk, 1981) was drawn up to check the answers of the previous question.

Question 12 was based on a question in Roos and Van Schalkwyk (1981).

Question 13 was based on a problem identified in a number of the researcher's classes.

Question 14 was included to gain feedback from the respondents.

As the aim of the pilot questionnaire was to generate alternatives which could be used to construct the two-tier multiple choice questionnaire, answers that were correct or had some degree of correctness were of lesser importance than those that were incorrect. Incorrect answers that were chosen by the majority of the pupils were used as well as those that were chosen by only a few pupils depending on their suitability. Consequently the discussion below will be concerned mainly with how the various answers and reasons in the test instrument were generated.

QUESTION 1

> If a tree is wounded and it heals its wound, would the scar formed be transferred to the seedling of this tree? Explain your answer.

The answer 'no' was given by 89% of the pupils, 7% answered 'yes' and 4% did not answer the question.

The reasons given for answering in the negative could be divided into four broad categories:

1. **Responses containing one or more of the terms: genes, chromosomes, genetic composition, inherited.** This group contained responses such as "No because the scar does not occur in the genes"; "It would not be carried in the chromosomes that a scar had occurred" and "it is not inherited but was wounded, so the seedling can't have it". 60% of the responses fell into this group. However, not all were entirely correct and some were vague such as "no, it wouldn't because it is not heredity". The correct response was selected from this group namely "The characteristics of the wound (later changed to scar) have not encoded in the tree's genetic make-up".

2. **Responses concerning the part of the tree wounded.** Only 4% of the responses fell into this category but the response "no, the bark of a tree does not play a part in reproduction", yielded reason (c).

3. **Responses concerning the wound.** These responses varied from "The scar will have healed before it could have been passed on" to "The wound would affect the cells of the tree if the wound was deep enough". The latter response was a reason for those who answered 'yes' as well. These responses were used to draw up answers 1 and 4 as well as reason (b).

4. **Responses which could not be categorised.** These made up 11% and included such responses as "the scar cannot be moved or transferred"; "... the other tree might not have a scar..." and "genes for a scar are not in the cells, they have merely healed."

Most of the reasons given for an answer in the affirmative concerned inherited characteristics. The reason "... all characteristics are inherited by the seedling" was used as reason (a).

QUESTION 2

> If the leaves of a plant are continually cut in half, will the plant eventually grow leaves that are shaped like the two halves instead of one whole leaf? Explain your answer.

In this question, the answer 'no' was given by 71% of the pupils, 'yes' by 25% and 4% of the pupils did not attempt the question.
The most popular response (46%) included the terms genes and genetic make-up. Reason (b) represents the most suitable of these.

The next most popular (12%) response concerned adaptations and mutations such as "Yes, because the tree adapts itself to the situation it finds itself in" and "yes, mutation will cause an altered form in the gene therefore the plant leaf will change". The former was used as reason (c) and the latter answer 2. An interesting response in this category was "yes, because it will become habit. The genetic composition of the leaf will divide instinctively". This certainly highlights the uncertainty surrounding genetics.

In similar vein, the response "yes, because the number of chromosomes are halved each time the leaf is cut in half" was used as reason (a) as it seemed to suggest a link to meiosis. Reasons concerning the structure of the leaf such as "yes, because the structure of the leaf is disturbed." and "...will cause an altered form in the gene therefore the plant leaf will change" were responsible for the inclusion of reason (d).

Answer 4 was included because of the response "The leaves will remain the normal leaf shape but the whole leaves will be smaller." It was assumed that 'narrower' was a more appropriate word considering the question.

The word 'lengthwise' was added to the question as a few of the respondents had queried the way in which the leaf was cut.

QUESTION 3.1

> If a tall man and a short woman have a son, how tall will he be when he is fully grown? Give a reason for your answer.

The answers given in response to this question were tall (34%), short (1%), of medium height (25%) or any height (35%). The remaining 5% did not answer the question. All four options were used as answer options to this question.

Only 25% of the pupils gave an explanation which included reference to genes or inheritance. These included reasons such as "depends on whose genes he has inherited" and "he will be taller than his mother, but shorter than his father because his genes will be half tall and half short". The former was used as reason (b).

The concept of dominant genes appeared in 31% of the reasons. These varied from "... depends on the dominant gene"; "tall because tall is dominant" to "the son will be either tall or short depending on which is dominant: tall or short". As these reasons appeared to be associated to Mendelian genetics, reason (a) simply stated 'tall is dominant over short'.

The dominance aspect was also related to the father for reasons such as "The son will have the dominant male characteristics and therefore be tall like the father" and "Tall: man is dominant". This option was catered for in reason (c).

Reason (d) was included to justify the choice of medium height and was a direct quote from one of the questionnaires.

Ratios, percentages and terminology directly associated with genetics were often quoted but these were omitted to ensure that the standard 8 group would not be disadvantaged.

QUESTION 3.2

> If the child is a girl, how tall will she be? Give a reason for your answer.

The answer options were the same as for question 3.1 but the percentages differed greatly: tall (10%), short (35%), of medium height (15%), any height from tall to short (35%) and 5% did not answer.

The responses were also similar to those given in question 3.1. The reasons given for the greater percentage choosing 'short' concerned the fact that the child was a female like the mother. These varied from "short is the dominant gene in females" to "The female species of the human is characteristically shorter than the male" and "... has more of the mother's genes". Reasons (a) and (c) were quoted from options such as these.

"The girl would be tall. Father's genotype is dominant" and similar such reasons were responsible for reason (d).

QUESTION 3.3

> Do you know of any other things which could make a child grow taller? Explain how your answer above makes the child grow taller.

Slightly fewer pupils (72%) answered this question. The explanations they gave fell into five categories:

1. **Responses involving the term 'genes' or related to genetics in some way** such as "Tall genes from parents ..." and "If his/her grandparents were both tall". This category was not used as the aim of the question was to test whether the pupil was aware of the influence of environmental factors.

2. **Responses concerning diet** were chosen by 20% of the pupils and generally an acceptable reason was given such as "Proteins promote growth". This response was included in option 3 (b). Reason (c) was included in case the connection between proteins and growth was not obvious.

3. **Responses involving the influence of hormones** such as "the more growth hormone that is secreted the taller the child will become" were used to draw up option 1 (a). This answer was chosen by 26% of the pupils.

4. **Steroids** was chosen by a few of the male pupils (8%) and as it was a topical answer, it was included as option 4 (d).

5. **Stretching exercises** (chosen by 4%) was an amusing answer so it was included as answer 2.

QUESTION 4

> A mouse born with no tail was mated with a normal tailed mouse. One mouse was born without a tail.
> How might that have come about?
> Can you explain why the litter contained some babies with tails and some without?

This question was omitted from the study questionnaire as it was generally correctly answered. The answers to question 4.1 included responses such as "one parent was heterozygous, one homozygous"; "...gene for no-tail recessive" and "1:1 ratio so some have tails". Question 4.2 was answered using similar reasons, some being more explicit ("not all babies received the defective gene") than others ("way in which the genes cross").

QUESTION 5

> State whether the following is true or false: sperm carries genes for half the features found in the offspring. Give a reason for your answer.

This question was correctly answered by 38% of the pupils, 58% answered 'yes' and 4% did not respond.

The reasons given were many and varied and consequently difficult to categorise. Some of the answers clearly showed the confusion experienced with this area of work. "Sperm ovulates the ovum but is not solely responsible for its development" and "it has to fuse with ovarie to make genes double" are prime examples.

The correct explanation "sperm carries all the features found in the offspring" was given by only 14% of the pupils. The genetics aspect appeared to influence the answers with 10% of the pupils mentioning it either as regards dominance ("it depends on whether the male's genes are dominant over the female or not") or chance ("sperm can carry all the genes or none at all for the offspring").

Reasons such as "½ the male genes combine with ½ female genes to form new (combined) being" and "the offspring contains 50% of the female's characteristics and 50% of the male's characteristics" represent 23% of the explanations. This reason was included as reason (c) in the study questionnaire. A further 5% related the halving of genes to meiosis and this was included as reason (d).

One of the responses stated that "genes are split up when sperm is formed" and as it appeared to be a confusion of the terms 'genes' and 'chromosomes', it was included to test the pupils' grasp of the terminology.

QUESTION 6

> What is the percentage chance of a baby born of two hybrid parents having the dominant trait? Explain your answer but do NOT do so using a diagram.

The correct answer of 75% was given by 34% of the pupils. Other answers given were 100% (9%); 50% (9%); 25% (3%); not much chance (8%) and no chance (1%). There was also a fairly high percentage who did not answer the question (37%). No significant misconceptions were generated, however, as the problems appeared to concern the mechanics of monohybrid crosses. Consequently this question was not included in the study questionnaire.

QUESTION 7

> Different cell types (skin, muscle, blood etc.) found in a person's body contain ..... sets of genes as the zygote. Explain why you filled in the word(s) you did above.

This question was characterised by a high percentage (65%) of pupils either not answering the question or doing so in such obscure terms that the answers could not be categorised. On analysis of the remaining 35% of the questionnaires, six categories were identified:

1. **'the same'** was chosen by 10% of the pupils and the correct reason was given such as "they are from the same person therefore the genes will be the same as the zygote". The wording of the correct reason (c) on the questionnaire was chosen to highlight the fact that this is so.

2. **'different'** was chosen by 9% of the pupils and various reasons were given such as "because the zygote consists of sperm and egg cells which are different" and "they are different cells with different functions therefore the sets of genes are different". The former reason was paraphrased and included as reason (b) and the latter was included as reason (d).

3. **'23'** was chosen by 8% of the pupils but was not included as originally this question was included in the standard 8 questionnaire and the number would have had no significance to them.

4. **'half'** was a response similar to that of '23' but was not seen to be worth including as only 2% of the pupils gave it as an answer.

5. **'twice as many'** was chosen by 5% of the pupils for a number of reasons including "the zygote has a diploid number of chromosomes"; "zygote will multiply 2 times" and the stating of Mendel's law of segregation. The first reason was seen as the most obvious one as far as the standard 10 and first year groups were concerned. It was included as reason (a) as no reason suitable for all three groups

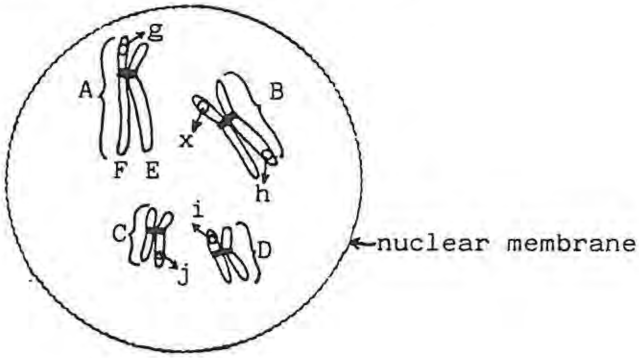
could be found.

6. **'homologous'** was chosen by only 1% of the pupils but as it could possibly be seen to link up with reason (a), it was included as answer 3.

The question was rephrased slightly to ensure that less confusion existed.

QUESTION 8.1

The diagram below represents four chromosomes in the nucleus of an organism's cell.




Write down the letters of two structures received from the organism's father. Explain your choice.

This question was answered by 62% of the pupils. Their answers were as follows: A & B (16%); A or B & C or D (14%); g & h/i & j (11%); C & D (11%); F & E (4%) and x & i/x & h/h & g (6%).

The four most popular answers were used as the answer options. The four reason options were chosen so that they linked to the various answers.

Reason (a) was a direct quote explaining why C and D were chosen. Similar reasons were given by other pupils. One unusual response was "The other two have already been in the mother, therefore they have grown bigger."

Reasons given for the choice of A and B varied from "... dominant over C and D" and "they are the biggest" to "homologous chromosomes". These reasons were included as reason (c).

Reasons to explain why letters representing genes were chosen all included mention of genes such as "because it is visible that they both have exchanged genetic material" This led to the formulation of reason (d).

No correct, concise reason was given for choosing the correct answer. "Because the genes mix with each other to form the zygote" and "mother and father both give ½ the number of chromosomes" are two examples of the type of reason given. Consequently reason (b) was not taken directly from the pilot questionnaire.

QUESTION 8.2

> Write down the letters of a homologous pair of chromosomes. Why did you choose those two?

Slightly more pupils (68%) answered this question and there was much less variety of answers. Only four different answers were given namely C & D (26%); A & B (19%); A & D (12%) and F & E (11%). As the first two were correct, A & B was chosen having been a popular choice in the previous question. A fourth option had to be provided so 'g and x' was chosen as, being alleles, they were the most closely related.

Reasons such as "they are exactly the same"; "both are identical" and "they share the same characteristics" were responsible for the inclusion of reason (a).

Reasons concerning the proximity of the chromosomes such as "the 2 chromosomes are next to each other forming double chromosomes" and "they lie next to each other" were incorporated in reason (b).

"They are the same size" was the closest to the correct reason and was used to formulate reason (c). Other reasons such as "Both got genetic material in top left hand corner" and "the chiasma and exchanged bits on both co-incide" showed a vague understanding of the term 'homologous'.

The behaviour of the chromosomes was used to draw up reason (d). The following reasons were used to do this: "they lie next to each other"; "they are fused at chiasmata" and "the crossing over is the same".

QUESTION 8.3

> If x represents the gene for blue eyes, where would you expect to find its allele? Explain your answer.

This question had a very poor response with 63% of the pupils failing to answer it. There were only four different answers, 1% of which "at the same place on the opposite chromosome" could not be used as it did not include a letter to illustrate it. Letters that were chosen were h (14%); g (10%) and i (2%). F was added to make up the fourth option as it appeared to be the most closely related to the correct answer.

Very few reasons were given. The correct reason was based on "because the 2 genes are situated at corresponding sites on a homologous pr of chromosomes". Reasons (b), (c) and (d) were quoted directly from the questionnaires and each one only occurred once.

QUESTION 9.1

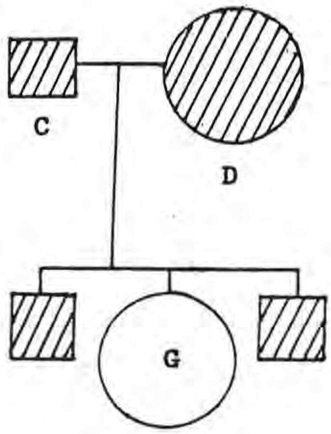
The diagram below shows the pedigree of a rabbit family:

*KEY:*

*squares = males*
*circles = females*

*shaded symbols = black fur*
*unshaded symbols = white fur*

*white fur is* ***recessive***




What is the genotype of G? Why is it that genotype?

Only 59% of the answers to this question were suitable for analysis. As letters were not provided for the two colours, the pupils had to choose their own. These were predominantly B and w/b or G and g. The correct answer was chosen by 40% of the pupils, while 11% said it was heterozygous and 3% homozygous dominant. A further 5% said it was a white female. These four options were presented as the possible answers, but the letters B and b were given in the key to prevent confusion.

There were various reasons many of which did not make sense. Consequently the four chosen do not represent the majority as there was none. Reason (a) was quoted directly as it represented confusion with the symbols used in questions such as these. Perhaps 'g' should have been changed to 'b' given the changed question. Reason (b) was the reason given for choosing Wb: "The white is dominant over black gene in this rabbit" and similar reasons were given by two other pupils. Reason (c) was also an isolated case but was included as it highlights the problem experienced with the genetic contribution of the parents. Reason (d) was the correct reason and as such was given by a number of the pupils in varying degrees of completeness. "Since white is recessive, it would have to be homozygous for the recessive gene" was the most complete.

QUESTION 9.2

> What does the genotype of G tell you about the genotype of C and D? Explain fully.

The responses to this question were placed in only three categories as 47% of the pupils either did not answer the question or did so in an obscure way such as "for every 2 males produced, only 1 female is produced". The correct answer was given by 38% of the pupils and was usually accompanied by a suitable explanation. This formed option 1 (b). Option 2 (c) was given by 9% of the pupils, although that reason was not always given. Answer 3 was given by 5% of the pupils and as reasons were seldom given, reason (d) was paraphrased from the reason "They must either both be hybrid or one must be hybrid and the other dominant (BB) ..." which seemed to explain the answer. Answer 4 was included as a fourth option was needed and it would be answered by pupils having difficulty with the symbols used in this type of question. The words 'its parents: C and D' were added to the question for clarity.

QUESTION 10

> The letter B represents the dominant gene for black colour in beetles, b the recessive gene for red colour. A red beetle is crossed with a homozygous black beetle. If a Punnet square is used to determine the offspring it would look like this:
>
> | | v | w |
> |---|---|---|
> | x | z | |
> | y | | |
>
> What letters would you place in squares v, w, x and y and why would you do it like that?
> What would be the genotype of the offspring marked z? How did you arrive at this answer?

Question 10 was not included in the study questionnaire as it was generally well answered. Question 10.1 did show some confusion but it was similar to question 11 which was included, so any misconceptions present would be identified by that question. Question 10.2 was correctly answered by 67% of the pupils who answered the question and a further 16% answered xv which showed confusion with the wording rather than the content of the question.

QUESTION 11

> The genotype for a certain characteristic is Tt. Indicate how the genes will be distributed in each of the four sex cells after the process of meiosis. Explain how you arrived at your answer.

This question was answered by 60% of the pupils. The four answers namely TT Tt Tt tt; Tt Tt; T T t t and 3 dominant to 1 recessive, were included as the four options in the study questionnaire. Option 1 was given by 36% of the pupils, option 2 by 6%, option 3 by 16% and option 4 by 2%.

Most of the reasons mentioned use of a diagram, one of which was quoted in reason (c). Other reasons mentioned how the diagram was used such as "by taking each letter out of the parent formula" which was used as reason (b). The correct reason (d) was not supplied by the pupils, the closest being "genes divide to form genes T and t which each form another sex cell identical to themselves". Reason (a) was included as a direct quote from one of the questionnaires as it was a delightfully confused account of gametogenesis.

QUESTION 12

> Seed obtained from a self-pollinated tall plant produced one relatively short plant. How do you explain this?

This question was not attempted by 35% of the pupils, correctly answered by 55% while 10% produced confused answers such as "these plants have different plants"; "there was a deformity in the genes" and "their genes differed in one seed". However, no general misconceptions could be identified so the question was omitted from the study questionnaire.

QUESTION 13

> When is Mendel's law of segregation applicable? Explain.

This question was answered by 58% of the pupils. 12% did so correctly, 24% merely stated the law of segregation, 12% named one of three inappropriate processes and the remaining 10% of the answers were too obscure to be identified ("during genetic crossings"; " when 2 plants with 2 sets of different genes produce seedlings, Mendel's law of segregation is applicable" etc.). The three processes were crossing over (5%), colour determination (4%) and determination of genotypes (3%). These were used as incorrect answer options in the study questionnaire.

There was no pattern amongst the reasons given by the pupils, so again the options used in the study were generally isolated examples. The correct reason varied from the simple such as "characteristics occurring in pairs become seperated & occur singly in the gametes. This occurs during meiosis ..." to the concise ("Allelic genes seperate during meiosis and are present in equal ratio in the gametes"). A paraphrased version was included as reason (d).

The reason explaining the choice of colour was given simply as "it is applicable to colour determination get mixed colours eg. plants" or more specifically "when you have recessive red & recessive white plants and when they cross you have pink plants in the offspring." These reasons were combined to form reason (a).

A few reasons concerned monohybrid crosses (presumably the 'crossing over' referred to, not in the meiotic sense) as they mentioned "when gametes are crossed" or "when crossing over of genes occurs ...". The former was used to draw up reason (b).

Reason (c) was a combination of two reasons: "when cross fertilisation takes place" and "in determining what type of offspring will occur" and it was included as it appeared to be the most likely explanation for the choice 'determination of genotypes'.

The question itself was reworded to prevent confusion as 'applicable' could have been taken generally whereas 'directly associated' was more specific.

QUESTION 14

What do **you** find most difficult about genetics?

This question was not answered by 27% of the pupils, 4% professed to having no difficulties and 69% listed one or two difficulties. The latter are summarised in Table 1. A discussion of these problems is included in chapter 6.

TABLE 1: Frequency and variation of perceived difficulties experienced in genetics

| RESPONSE | FREQUENCY |
|---|---|
| Determining genotypes | 16% |
| Understanding the whole concept | 12 |
| Terminology | 9 |
| Explaining answers | 8 |
| Applying Mendel's laws | 5 |
| Understanding diagrams, symbols and letters | 5 |
| Understanding dominance | 5 |
| Cell division | 5 |
| Dihybrid crosses | 4 |

**TWO-TIER MULTIPLE CHOICE QUESTIONNAIRE**

A trial draft of the multiple choice questionnaire (appendix B) was drawn up using the answers and reasons generated in the pilot questionnaire and one further question was added to include the aspect of chance.

The draft questionnaire was critically evaluated by 3 teachers and 3 lecturers and the following modifications were made:

1. The word 'wounded' in question 1 was replaced by 'damaged' as it was seen to be more suitable for a plant.

2. The word 'damage' in reason (b) of question 2 was changed to **physical** damage to be more specific and so rule out damage from radiation which would affect the genetic composition.

3. The words 'chromosomes carrying' were added to question 4 to ensure that the intention of the question was clear. Reasons (b) and (d) for this question were rephrased so that they were clearly incorrect. The question was then numbered 5 so that it did not form part of the standard 8 questionnaire.

4. Question 5 was changed to question 4 and reworded so that it did not include any terms foreign to the standard 8 group.

5. Reason (a) in question 6.2 was reworded so that it was obviously incorrect.

6. The words 'in reality' were added to question 9.3 so that it was clear the question was not dealing with theoretical ratios. Reasons (a) and (c) were reworded more strongly by including the words 'always' and 'has to be' respectively to ensure that the reasons were clearly incorrect.

The aim(s) of the various questions in the final draft of the questionnaire (appendix C) were as follows:

Questions 1 and 2: To discover whether the pupils are aware of the fact that plants do reproduce sexually and whether they realise what this entails as regards genes and the transmission of characteristics.

Question 3: To examine the pupils' conception of the transmission and contribution of genes in a simple genetics exercise.

Question 4: To examine the pupils' conception of the transmission of genes as linked to sexual reproduction rather than genetics.

Question 5: To discover whether the pupils are aware that <u>every</u> cell contains a complete set of genes.

Question 6: To discover whether pupils are aware that every chromosome has a partner which was received from the opposite sex parent and that each pair is made up of homologous chromosomes bearing pairs of genes for particular characteristics on corresponding sites.

Question 7: To examine the pupils' ability to understand the processes underlying a genetics exercise which is usually solved by a Punnett diagram.

Question 8: To discover whether or not Mendel's law of segregation can be directly linked to the movement of chromosomes during meiosis.

Question 9: To examine the pupils' reasoning when required to solve a genetics problem and whether they are aware of the element of chance involved.

An answer sheet (appendix D) was drawn up to accompany the questionnaire. The answer sheet was shortened to include space for answering questions 1 to 4 only for the standard 8 group (appendix E).

# CHAPTER 5

## ANALYSIS OF RESULTS

For convenience, the results will be examined question by question concentrating on similarities and differences between the three groups (std 8, std 10 and first year university). This will be done by examining the percentage of responses in the various options. The percentages were calculated on the assumption that there were 110 subjects in standard 8, 88 in standard 10 and 52 in first year university. Occasional questions or parts of questions were omitted, but as these omissions seldom counted for more than 1 or 2 percent, they were not seen to play a relevant part in altering the results as calculated. Generally only percentages of 10% and above will be discussed. Tables showing the exact number of responses for each option for the various questions are presented in appendix F. It is not necessary to consider the sex of the respondents as it was found to have no statistical significance.

### QUESTION 1

If a tree is damaged and it heals its wound, how would the scar affect the seedling of this tree?

1. It would not affect the seedling if the scar heals before the seeds are formed.
2. The seedling would be scarred.
3. The seedling would not be affected.
4. The seedling would only be affected if the scar was very deep.

REASON

(a) The seedling inherits ALL the characteristics of the tree.

(b) A deep wound will affect the cells and consequently the seedling.

(c) Bark is not involved in reproduction so the seeds will not be affected.

(d) The characteristics of the scar are not encoded in the genetic make-up.

(e) . . . . . . . . . . . . . (own reason)

TABLE 2: Analysis of response options for QUESTION 1 expressed as percentages

| | STD 8 | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | 14 | 11 | 5 |
| RESPONSES: 3 d* | 29% | 44% | 60% |
| 3 c | 24,5 | 29,5 | 25 |
| 4 b | 19 | 7 | 8 |

* correct answer and reason combination

The choice of answers selected for question 1 were found to be statistically different (d.f. = 6, $p < 0,001$) which leads one to conclude that with age or more probably further education, pupils **do** realise that physical damage to a plant cannot be inherited by its seedlings.

This question could have been incorrectly answered for a number of reasons, the most likely being an inability to fully understand the mechanism of sexual reproduction in plants. The younger pupil especially has difficulty distinguishing between healing a wound and producing seeds. This fact could be carried through to the older pupils despite the fact that they have studied mitosis and meiosis. It could confuse the issue of distinguishing between cells and genes and the role of each in growth and development. By first year university, however, one would expect the subject to be able to distinguish between seeds and genetic make-up as was generally found to be the case in this study.

QUESTION 2

If the leaves of a plant are continually cut in half lengthwise, what will eventually happen to the new leaves produced by that plant?

1. The new leaves will be shaped like the two halves instead of the whole leaf.
2. A mutation will occur.
3. The shape of the new leaves will be unaffected.
4. The leaves will be narrower.

REASON

(a) The number of chromosomes will be halved each time the leaf is cut.

(b) The genotype is not affected as physical damage done to the plant is not inherited.

(c) The tree adapts itself to the new situation.

(d) The genes that influence the shape of the leaves are damaged.

(e) . . . . . . . . . (own reason)

TABLE 3: Analysis of response options for QUESTION 2 expressed as percentages

| | | STD 8 | STD 10 | FIRST YEARS |
|---|---|---|---|---|
| OPTIONS USED (max. 20) | | 16 | 15 | 8 |
| RESPONSES: | 3 b* | 46% | 64% | 69% |
| | 2 c | 11 | 8 | 13.5 |
| | 4 c | 7 | 8 | 6 |

* correct answer and reason combination

There was no statistical difference between the responses from the three groups of subjects for question 2. The fact that the plant was **continually** cut appears to have some influence on the choice of answer.

The standard 8 pupils have been exposed to the concept of natural selection which introduces them to the concept of change in response to environmental factors and this could have swayed some of them to chose 2 c. This shows a knowledge of the process rather than the actual mechanics. The fact that 13,5% of the first years chose this option is unexplained. It does, however, question the seriousness with which the subjects approached the questionnaire.

The fact that some subjects, albeit less than 10%, chose option 4 c is worth mentioning in that behaviour rather than the contribution of genes was considered. This could have been caused by the subjects equating the behaviour of animals to plants. This fact is borne out by other questions which will be discussed later.

QUESTION 3.1

If a tall man and a short woman have a son, how tall will he be?

1. As tall as his father.
2. Short like his mother.
3. Of medium height.
4. Any height from tall to short.

REASON

(a) Tall is dominant over short.

(b) His height will depend on the genes he inherits from his parents.

(c) He is a boy so he has the same genes as his father.

(d) He has half his father's tall genes and half his mother's short genes, so he will be of medium height.

(e) . . . . . . . . . (own reason)

TABLE 4: Analysis of response options for QUESTION 3.1 expressed as a percentage

| | STD 8 | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | 8 | 6 | 5 |
| RESPONSES: 4 b* | 75% | 81% | 90% |
| 4 e | 8 | 6 | 4 |
| 4 d | 7 | 4,5 | 0 |

* correct answer and reason combination

This question was well answered by all three groups. The correct answer was chosen by 85% of the standard 8's, 86% of the standard 10's and 96% of the first years. The fact that quite a number of pupils chose to give their own reason (4 e - see Table 4) distorted the results slightly. Many of the reasons given were correct but not always succinct, and varied from "depends on which parent has the dominant gene" to "determined totally by genes".

Kargbo, Hobbs and Erickson (1980) found that young pupils believed that the same-sex parent determined the height of the child. This was believed to be due to a naturalistic conceptual framework which was characteristic of children under ten years of age. Although this answer was found in the pilot questionnaire, there were no responses for this option in question 3.1. There was, however, a small percentage in each of the groups who chose the option in connection with the mother (question 3.2). This discrepancy is difficult to explain. Another discrepancy is evident in that only a very small percentage chose reason d which would have shown uncertainty regarding the contribution of genes, although this problem is evident in later questions.

QUESTION 3.2

If their child is a girl, how tall will she be?

1. As tall as the son.
2. Of medium height.
3. The same height as the mother.
4. Any height from tall to short.

REASON

(a) She is a girl with XX sex chromosomes so she will inherit her mother's characteristics.

(b) The genes inherited from both parents determine the child's height.

(c) Females are characteristically shorter than males.

(d) The father's genotype is dominant.

(e) . . . . . . . . . (own reason)

TABLE 5: Analysis of responses for QUESTION 3.2 expressed as percentages

| | STD 8 | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | 9 | 12 | 6 |
| RESPONSES: 4 b* | 69% | 75% | 83% |
| 2 b | 9 | 3 | 6 |

* correct answer and reason combination

The correct answer for this question was chosen by a slightly lower percentage (std 8 - 79%, std 10 - 85% and first years - 85%) of the subjects than question 3.1 despite the fact that it was virtually the same question. The choice 'medium height' seemed more acceptable than in the previous question perhaps due to the fact that women on average are seen to be shorter than men.

QUESTION 3.3

Do you know of any other things that could make a child grow taller?

1. Growth hormones
2. Stretching exercises
3. A diet high in protein foods
4. Steroids

REASON

(a) Hormones regulate the metabolism of the body.

(b) Proteins enable growth to occur.

(c) The more one eats, the taller one grows.

(d) Muscle growth is increased making the child bigger.

(e) . . . . . . . . (own reason)

TABLE 6: Analysis of responses for QUESTION 3.3 expressed as percentages

| | STD 8 | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | 10 | 7 | 4 |
| RESPONSES: 1 a* | 64% | 73% | 81% |
| 1 e | 8 | 10 | 14 |
| 3 b | 11 | 2 | 0 |

* correct answer and reason combination

It was hoped that this question would demonstrate the importance of environmental factors such as diet. However, the question was not specific enough to do this as growth hormones influence growth as well. The question should have read "what **other** factors besides genes, influence growth?" Nonetheless the question was generally correctly answered and it was gratifying to read the one response in standard 10: "growth is predetermined by hormones and genes and retarded by malnutrition". This shows a greater depth of insight than many of the responses.

A possible reason for the fact that question 3 was generally well answered could be due to the nature of the question. Pupils are more likely to understand questions concerning people than they are plants. Carey (1985) suggested that children have a people prototype in that they imbue human characteristics to animals (in her study mammals, birds, insects and worms) according to how closely they are seen to be related to humans. Mammals were found to be 'most human' while worms had no human characteristics. In the same way, plants were seen to be divorced from humans and consequently they could not have any similarities. For instance, it has been found (Okeke and Wood-Robinson, 1980) that plants are thought to be unable to reproduce sexually. This could explain why questions 1 and 2 were not as well answered as question 3. This transference of characteristics is evident in question 2 as previously mentioned.

QUESTION 4

Sperm cells and egg cells contain chromosomes which carry 'instructions' (in the form of genes) necessary to 'build' a new individual. Is it true to say that a sperm cell carries **some** of these while the egg cell carries the remainder which are different to those of the sperm?

1. It is true.
2. It is NOT true.

REASON

(a) Sperm and egg cells carry one or more genes for every feature in the new individual.

(b) Sperm and egg cells each contain half the number of chromosomes as body cells, so they each carry half the 'instructions' (genes) needed to produce a new individual.

(c) The new individual may have some of the mother's features and some of the father's, so the egg and sperm cells obviously carry different 'instructions' (genes).

(d) Sexual reproduction involves a sperm and an egg cell so the new individual must get half of its 'instructions' from the father and the rest from the mother.

(e) . . . . . . . . (own reason)

TABLE 7: Analysis of responses for QUESTION 4 expressed as percentages

| | | STD 8 | STD 10 | FIRST YEARS |
|---|---|---|---|---|
| OPTIONS USED (max. 10) | | 10 | 9 | 6 |
| RESPONSES: | 2 a* | 4.5% | 14% | 31% |
| | 2 b | 12 | 21,5 | 21 |
| | 2 c | 12 | 10 | 0 |
| | 1 b | 22 | 8 | 19 |
| | 1 c | 38 | 26 | 15 |

* correct answer and reason combination

There was a great diversity of answers to this question with a very low percentage of pupils choosing the correct answer/reason combination. This could be due to the fact that this question is too complex to pinpoint any misconceptions. Ideally the question should have been broken into three or four questions so that specific problems could be highlighted. Possibly the wording of the question resulted in the high percentage of pupils in standards 8 and 10 choosing option 1 c. There is a tie up with the word 'some' in the question and the answer. Furthermore, the interpretation of the word 'different' could have been seen as alternative which is correct in the sense that the parents may have different genes for the same characteristic. The standard 10 pupils, having done a course in genetics, should not have been swayed by this tie up, however.

Statistically the answers and reasons from the three groups differ (d.f. = 2, p < 0,001)(d.f. = 2, p < 0,001). In addition, the fact that 60% of the standard 8 pupils chose answer 1 does suggest that there are likely to be problems regarding the link between sexual reproduction and genetics. It is felt that this particular area warrants further study.

QUESTION 5

When compared to a zygote, different cell types (skin, muscle, bone etc.) contain chromosomes carrying . . . . . genes as the zygote.

1. the same
2. different
3. homologous
4. twice as many

REASON

(a) Only the zygote has a diploid number of chromosomes; after meiosis the number becomes haploid.

(b) Different cell types have different genes because they produce cells which differ in appearance.

(c) The zygote contains all the genes needed to form a new individual

(d) The zygote is formed from an egg and a sperm cell so it has not got the same genes as skin cells etc.

(e) . . . . . . . . (own reason)

TABLE 8: Analysis of responses for QUESTION 5 expressed as percentages

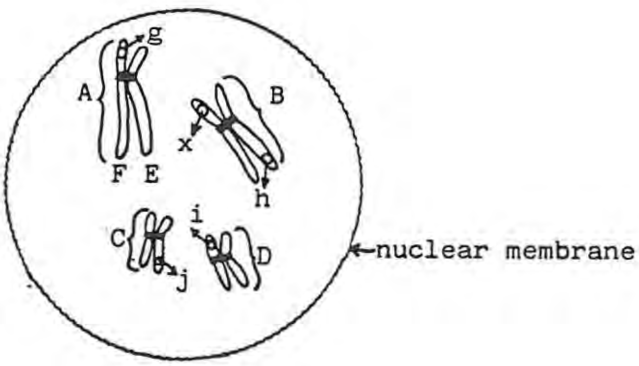
| | | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | | 16 | 8 |
| RESPONSES: | 1 c* | 25% | 69% |
| | 1 e | 3 | 13,5 |
| | 4 a | 16 | 0 |
| | 4 d | 10 | 2 |

* correct answer and reason combination

Only 33% of the standard 10 pupils chose answer 1 which showed that they realised that the zygote has the same genetic composition as the other cells. The rest of the group appear to regard the zygote as something special and unrelated to the other cells of the body. This fact could seriously hamper areas of work such as plant life cycles, genetics and sexual reproduction (embryology particularly). In the latter case, the pupil will find it difficult to explain how a single cell gives rise to many millions of differentiated and specialised cells. However, the results of the two groups were found to be statistically different as regards both the answers (d.f. = 3, $p < 0{,}001$) and the reasons (d.f. = 5, $p < 0{,}001$), so this is one misconception which does appear to be dispelled by further tuition.

QUESTION 6.1

The diagram below represents four chromosomes in the nucleus of an organism's cell.




The following structures were received from the organism's father:

1. A and B
2. A and D
3. i and j
4. C and D

REASON

(a) The father's sperm is smaller than the ovum.

(b) One chromosome from each bivalent is found in the sperm cell.

(c) The bigger chromosomes come from the father.

(d) They are homologous chromosomes so they can exchange genetic material

(e) . . . . . . . . . (own reason)

TABLE 9: Analysis of responses for QUESTION 6.1 expressed as percentages

| | | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | | 14 | 11 |
| RESPONSES: | 2 b* | 10% | 36% |
| | 2 d | 11 | 6 |
| | 3 b | 11 | 11,5 |
| | 3 d | 16 | 10 |
| | 1 c | 14 | 10 |

* correct answer and reason combination

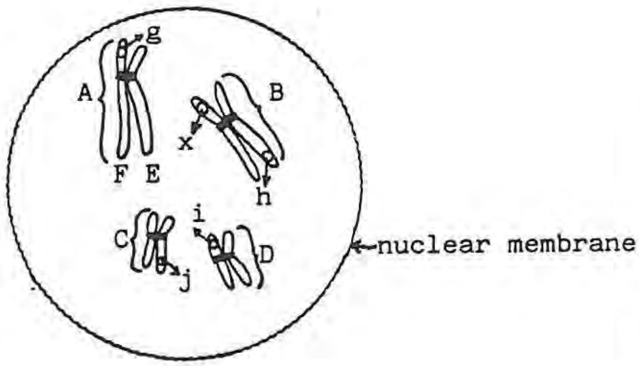
There is a statistical difference (d.f. = 4, $p < 0{,}001$) between the choice of answers by the two groups for this question. The standard 10 group had a particularly low percentage who chose the correct answer (21%) with only 10% linking it to the correct reason. Reason d was more popular (11%). Despite the statistical difference, only 44% of the first years chose the correct answer with 6% linking it to reason d which is incorrect. A possible reason for choosing reason d, by the standard 10's particularly, could be an inability to link meiosis and the genetic composition of body cells - a problem identified in question 5. Consequently the pupils chose a reason which is familiar to them and which they can link to meiosis.

The fact that 31% of the standard 10 group chose answer 3 which depicts genes and not chromosomes, shows that the pupils could be experiencing a problem with terminology. It has been found (Stewart, 1982) that pupils do find it difficult to distinguish between genes, chromatids and chromosomes. Another possible explanation could be that the pupils chose answer 3 because of the connection between 'received from the organism's father' (taken to mean **inherited**) and the **genes** i and j on the chromosomes. This problem could arise from the fact that the genetics section that is taught in school deals almost exclusively with genes; chromosomes are seldom mentioned. It would be assumed that by the end of the first year level genetics course, this would no longer be a problem and yet 25% of the students chose answer 3. This suggests quite a deeply embedded problem.

It is alarming to note that 14% of the standard 10 group and 10% of the first years chose option 1 c. The tendency to associate male with big was not evident in questions 3.1 and 3.2, so it is unexpected to find it here. The response percentages are **too** high to explain it as a lack of seriousness on the part of the subjects, so it can only be seen as a regression to the 'dominant male stereotype', the problem that was expected to arise in question 3.1 but did not.

QUESTION 6.2

The diagram below represents four chromosomes in the nucleus of an organism's cell.




The following two structures represent a homologous pair of chromosomes:

1. A and B
2. F and E
3. A and D
4. g and x

REASON

(a) They have identical genes.

(b) They are found close to each other.

(c) They are similar in size and shape.

(d) They lie next to each other, become attached at the chaisma and exchange genetic material.

(e) . . . . . . . . (own reason)

TABLE 10: Analysis of responses for QUESTION 6.2 expressed as percentages.

| | | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | | 13 | 11 |
| RESPONSES: | 1 c* | 11% | 21% |
| | 1 a | 12,5 | 11,5 |
| | 1 d | 8 | 15 |
| | 2 d | 32 | 25 |

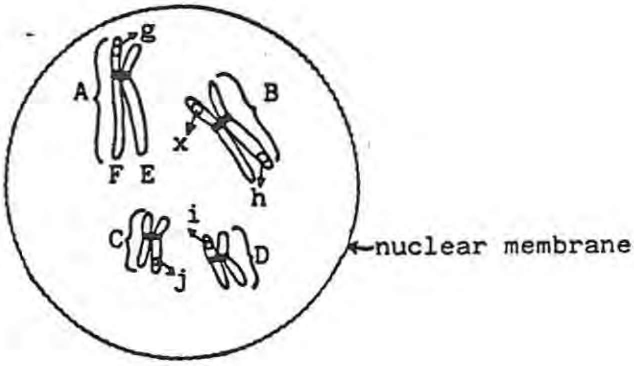
* correct answer and reason combination

The most popular option for both groups was 2 d (see table 10) which are the two chromatids of one chromosome, not two homologous chromosomes. This again bears out the problem with terminology. The problem could be bound up in the way in which meiosis is taught and the role of replication in the process. If chromosomes are seen to consist of a single strand which only forms two (after replication) so that they can be sent to the two daughter cells, problems are bound to arise when one considers homologous pairs. In the same way, the fact that homologous pairs are formed mainly so that genetic material can be swopped, could distort the pupil's view of the situation.

The correct answer was chosen by only 32% of the standard 10 group and 54% of the first years with relatively low percentages choosing the corresponding correct reason (see Table 10), the first years preferring reason d and the standard 10's reason a. The latter fact could point to a problem when one considers the link up between homologous chromosomes and homo- or heterozygous. It would have been interesting to see whether that was still the preferred choice if genes had been mentioned in reason c such as "they are similar in size and shape and carry genes for the same characteristics".

QUESTION 6.3

The diagram below represents four chromosomes in the nucleus of an organism's cell.




If x represents the gene for blue eyes, its allele would be found at ...

1. g
2. h
3. i
4. F

REASON

(a) Alleles are found on a corresponding site on other chromosomes.

(b) Alleles are found on chromosomes of the genes.

(c) Alleles are found on the opposite side of the chromosome.

(d) Alleles are found on the same sets of chromosomes.

(e) . . . . . . . . (own reason)

TABLE 11: Analysis of responses for QUESTION 6.3 expressed as percentages

| | | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | | 14 | 8 |
| RESPONSES: | 1 a* | 20% | 48% |
| | 2 a | 26 | 21 |
| | 2 c | 11 | 8 |
| | 2 d | 12,5 | 8 |

* correct answer and reason combination

The correct option percentage is again low especially for the standard 10 group (see Table 11). Answer 2 was the most popular (std 10: 51%; first years: 37%) but only 26% and 21% respectively linked it to the correct reason. Again the problem of distinguishing between a chromosome and a chromatid is highlighted. The problems experienced with terminology do appear to be carried over to university level, although the degree of severity appears to have lessened. It remains a problem nonetheless.

## QUESTION 7

The genotype for a certain characteristic is Tt. How will the genes be distributed in each of the four sex cells produced by meiosis?

1. TT Tt Tt tt
2. Tt Tt
3. T T t t
4. 3 dominant to 1 recessive (ratio 3:1)

REASON

(a) The number of chromosomes is doubled, each gene divides once and then in half so that there are 4 single genes, one in each gamete.

(b) The answer can be reached by taking each letter out of the parent formula.

(c) By using a diagram to cross the genes.

(d) The genes are separated into two cells, one with T and the other t which then form another sex cell during the second meiotic division.

(e) . . . . . . . . (own reason)

TABLE 12: Analysis of responses for QUESTION 7 expressed as percentages

| | | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | | 17 | 13 |
| RESPONSES: | 3 d* | 4,5% | 13,5% |
| | 3 a | 2 | 23 |
| | 1 c | 25 | 31 |
| | 4 c | 15 | 8 |

* correct answer and reason combination

Despite the low success rate for this answer, the fact that 23% of the first year group chose option 3 a (the correct answer but the wrong reason) is the most disturbing. The reason was given by only one pupil in the pilot questionnaire and it was included as it contains two blatantly unsound statements ('the number of chromosomes is doubled' and 'each gene divides'). Enough students chose it to rule out a possible lack of seriousness. It would be interesting to examine the way in which the university lecturers approach monohybrid cross exercises to see whether this discrepancy can be accounted for.

The most popular option for this question was 1 c. This shows some understanding of the mechanics behind monohybrid cross exercises but little understanding of the reasons for doing them. The fact that 15% of the standard 10 group chose option 4 c further emphasises the tendency to cling to rote learnt facts with little understanding of what these facts mean. The responses to this question show that the subjects have little understanding of the processes involved in genetics so perhaps it is understandable why they have problems linking genetics to meiosis as has been previously discussed.

QUESTION 8

With what process is Mendel's law of segregation directly associated?

1. Meiosis
2. Crossing over
3. Colour determination
4. Determination of genotypes

REASON

(a) A plant with red flowers is crossed with one with white flowers to produce one with pink flowers.

(b) It explains how gametes are crossed.

(c) When cross fertilisation occurs it shows what type of offspring will occur.

(d) During the production of sex cells, genes on bivalent chromosomes are separated from each other.

(e) . . . . . . . . (own reason)

TABLE 13: Analysis of responses for QUESTION 8 expressed as percentages

| | | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | | 17 | 13 |
| RESPONSES: | 1 d* | 6% | 23% |
| | 4 c | 14 | 23 |
| | 3 a | 19 | 13,5 |
| | 2 a | 14 | 8 |
| | 2 b | 11 | 2 |

* correct answer and reason combination

The responses to question 8 show that there definitely is a problem linking genetics to meiosis as has been previously suggested. Here too there is an uncharacteristically high percentage of first years choosing option 4 c as opposed to the standard 10 group. This again suggests the university genetics course should be investigated in an attempt to find a reason for this anomaly.

Apart from the inability to see the cross-links when doing genetics exercises, the response option 3 a raises an issue which has not been considered to date - a tie up between colour and genetics exercises. Despite the obvious examples used to explain the work of Mendel and Correns (green and yellow seeds and red and white flowers respectively), many of the textbook examples also concern colour such as the coat colour of guinea pigs and horses and the body colour of fruit flies. This appears to have led to a strong association of colour and genetics which jeopardises certain pupils' ability to make other, more significant links.

QUESTION 9.1

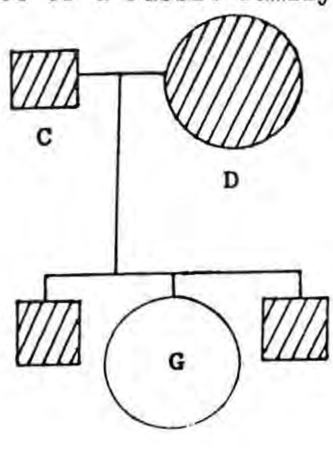
The diagram below shows the pedigree of a rabbit family.

KEY

squares = males
circles = females

shaded symbols = black fur (B)
unshaded symbols = white fur (b)

white fur is **recessive**



What is the genotype of G?

1. BB
2. Bb
3. bb
4. a white female

REASON

(a) G is female and g is a recessive gene.

(b) White is dominant over black in this rabbit.

(c) One of the parents had recessive genes.

(d) The gene for white fur is recessive so all white rabbits must be homozygous.

(e) . . . . . . . . (own reason)

TABLE 14: Analysis of responses for QUESTION 9.1 expressed as percentages

| | | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | | 18 | 7 |
| RESPONSES: | 3 d* | 23% | 73% |
| | 3 c | 11 | 8 |
| | 2 c | 12,5 | 6 |

* correct answer and reason combination

In this question, the standard 10 responses were very diverse (see Table 14) and only 23% chose the correct option. The first year group fared much better in that there was much less diversity and 81% chose the correct answer, 73% coupling it to the correct reason. The choice of answers was not statistically different while that of the reasons was (d.f. = 4, $p < 0,001$). This could have been due to the difference in diversity of answers.

The way in which the standard 10 group answered this question shows very little depth of understanding regarding monohybrid crosses. There is very little understanding of what a recessive characteristic is and its significance. Furthermore, although there is a general idea of how to approach a monohybrid cross exercise, one wonders if this is due to practice rather than understanding of the underlying processes. Judging by the results of questions 7 and 8, it is the former.

QUESTION 9.2

What does the genotype of G tell you about the genotype of its parents, C and D?

1. They are both heterozygous.
2. They both have black fur.
3. One has recessive genes.
4. One is a male and one is a female.

REASON

(a) G was produced when a sperm cell fused with an egg cell.

(b) G is homozygous as it obtained one gene for white fur from its mother and the other from its father.

(c) Black fur is dominant.

(d) The parents are hybrids so they produced a hybrid offspring.

(e) . . . . . . . . . (own reason)

TABLE 15: Analysis of responses for QUESTION 9.2 expressed as percentages

| | | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | | 14 | 8 |
| RESPONSES: | 1 b* | 27% | 69% |
| | 2 c | 12,5 | 0 |
| | 3 b | 12,5 | 19 |

* correct answer and reason combination

Of the first year group, 86,5% chose the correct answer 1 but the associated reason varied from a to e with 69% choosing the correct reason b. Only 27% of the standard 10 group chose the correct answer/reason combination resulting in a statistical difference (d.f. = 4; $p < 0,001$) between the two groups. This suggests that following instruction at a tertiary level, the conception of homologous chromosomes is changed.

The next most popular choice amongst the standard 10 group was either 2 c or 3 b (see Table 15). The former choice shows that either the question was not read correctly or again terminology is a problem as phenotype was given and not genotype as asked. The choice of 3 b shows that they are aware of the fact that G has the recessive characteristic and that it is inherited as the correct reason was given. This mistake could be due to the fact that the contribution of genes from each parent is unclear - a problem noted in question 4, although it is more likely that the term recessive is not understood. The pupils seem unaware that if the offspring is recessive, both parents must carry the recessive gene. This problem was experienced by 6% of the first years as well. It could also have been a contributory factor in the low success rate in question 9.1.

<u>QUESTION 9.3</u>

> If E and F both have the genotype Bb, in reality what could be the genotype of a fourth baby rabbit?
>
> 1. BB
> 2. bb
> 3. Bb
> 4. either BB, Bb or bb

REASON

(a) The parents are heterozygous so they will always produce babies in the following genotypic sequence: BB, Bb, Bb and bb.

(b) The parents are heterozygous black so they will produce 3 black babies for every one white one.

(c) There is a 75% chance of the babies being black, so the fourth baby has to be black as there are only 2 black babies so far.

(d) Chance will determine the genotype of the offspring and there are three possiblilities as both the eggs and the sperm carry either a white gene or a black gene.

(e) . . . . . . . . (own reason)

TABLE 16: Analysis of responses for QUESTION 9.3 expressed as percentages.

| | | STD 10 | FIRST YEARS |
|---|---|---|---|
| OPTIONS USED (max. 20) | | 15 | 11 |
| RESPONSES: | 4 d* | 29,5% | 38,5% |
| | 4 a | 18 | 17 |
| | 1 a | 12,5 | 19 |

* correct answer and reason combination

The correct answer for this question was chosen by 59% of the standard 10 group and 58% of the first years with only 29,5% and 38,5% respectively, coupling it to the correct reason. The fact that reason a was fairly popular (see Table 16) shows a tendency to believe that the four blocks of the Punnett square represent the sequence in which the offspring are born. The responses to this question lead one to assume that genetics is viewed as a textbook theory that is divorced from reality. In consequence, chance, a concept seldom associated with science, cannot be equated with it and so is seldom considered.

Finally it should be noted that question 9 hinges on an ability to understand the 'family tree' diagram. Problems associated with these three questions could merely have arisen through an inability to interpret the symbols. One would assume, however, that by standard 10 and first year level this would only be a problem for a few pupils not the majority.

Mention should be made at this point of the effect of the research method on the respondents' attitude to the questionnaire. Both the standards 8 and 10 group were in a classroom situation which is synonymous with academic work. The questionnaire was handed out by the teacher who is a figure of authority and consequently it is assumed that the answers were fairly representative of their ability but that the pupils who normally buck the system could quite likely have answered falsely merely to complete the questionnaire.

The university students on the other hand completed the questionnaire during a practical and as the questionnaire was neither handed out nor stipulated to be compulsory, the response was poor. It is felt, however, that the respondents who did complete the questionnaire were more likely to do so honestly. It is felt that the approach used in this study was the most natural and consequently, the most likely to elicit genuine responses.

# CHAPTER 6

# DISCUSSION

## INTRODUCTION

This study was aimed at identifying misconceptions held by the pupil and consequently teacher-related problems were not considered. It must be mentioned, however, that it is possible that some of the problems identified could stem from the teacher and could include such factors as competence with and perceived relevance of genetics (Longden, 1982). Genetics is a relatively modern and dynamic area of study. For example, the structure of DNA was established only in the 1950's. Consequently, some of the teachers who are in their fifties, may not feel comfortable teaching anything other than classical genetics. Although such problems fall beyond the scope of this study, once commonly held misconceptions have been isolated, an investigation into teaching methods could prove informative as therein lies the most likely solution to the problem.

## CONCEPTUAL DEVELOPMENT

The three groups of respondents in this study were specifically chosen to illustrate the conceptual frameworks of pupils before any tuition in genetics, a year after a basic introductory course and directly after a more intensive course in genetics.

The standard 8 group in this study had not dealt formally with these subjects. They had, however, been exposed to such terms as genes, chromosomes and DNA when they studied the structure of the cell in the standards 7 and 8 Biology courses. In addition, brief mention had been made of cell division in the standard 8 course and sexual reproduction of selected plants and animals had been covered in the standards 6 and 7 courses. Consequently, the standard 8 group's conception of genetics arises from preconceived ideas gained in everyday life which could perhaps have been influenced to a degree by related school work.

Despite the lack of formal education, only two of the six questions (questions 1 and 4) produced results that were statistically different from the other two groups. It would seem that formal education does not change all of the pupils' conceptions to a great extent. Some misconceptions appear to be so deeply ingrained that tuition does not change them. For example, the results in question 2 show that despite education, misconceptions regarding sexual reproduction in plants are still present at a tertiary level.

The standard 10 group had received tuition in genetics, cell division and both human and plant reproduction in standard 9. The work done in the standard 10 course does not link in with these courses to a great extent. The biochemical study of proteins mentions protein synthesis and the associated role of DNA and chromosomes, but no association with genetics is mentioned. Similarly, population dynamics could be linked to genetics but again no mention is made of this. When answering the questionnaire, the standard 10 pupils therefore relied on their ability to recall work done almost a year previously. This had the advantage of testing long-standing conceptions.

Researchers such as Osborne and Wittrock (1985) believe that concepts will soon be forgotten if they are not linked to a sufficient number of concepts in the child's cognitive framework. If this is the case, the difficult to understand concepts are unlikely to be remembered a year later. This could perhaps account for the statistically different answers generated in questions 9.1 and 9.2. The first year students, having done the work only 3 months previously, are more likely to remember what recessive characteristics and homologous chromosomes are.

At university genetics is dealt with towards the end of the first semester and is tested in the mid-year examinations. Consequently, even facts learnt by rote should be able to be recalled. Despite this advantage, the students did not fare any better than the standard 10 pupils in some questions. Question 8 is a good example of this. This question asked for a straight forward link between Mendel's law of segregation and meiosis, but was incorrectly answered by many nonetheless.

Novak (1978 in Stewart and Dale, 1981) believes that it is a lack of appropriate cognitive preparation rather than a lack of intrinsic ability to think at a formal level, that is responsible for the failure to understand genetics. This could be true in that genetics encompasses a number of concepts that are new to pupils and as they are also abstract, they may be difficult to grasp. The results of this study, however, cannot be explained so simply in that some of the questions were well answered and others not, regardless of the age or educational level of the respondent. It is felt that the preconceived notions held by the pupils are one of the biggest stumbling blocks in the successful mastery of the subject.

It is obvious from the responses of the standard 8 group that certain preconceived ideas equivalent to the alternative frameworks, mini-theories etc. discussed in chapter 2 do exist. These could be changed during the course of learning as is the case for questions 1 and 4, or remain intact as typified by question 2. This leads one to consider reasons for the steadfastness of these ideas.

One reason could be that pupils find it threatening to change their mental schema so they resist it. This means that the new information will only be linked to a few concepts and soon forgotten. This could be one of the reasons why the standard 10 group did not do as well as the university students in some questions. As previously mentioned, Osborne and Wittrock (1985) believe that if too few links are generated due to insufficient testing, learning will not occur and alternately the more links generated, the better the work is remembered. In addition, wrong links could be made and these will lead to misconceptions. An example of this could be the linking of colour to genetics exercises in question 8 which jeopardises correct links being made.

The generating of these links is a personal matter which results in different pupils learning different things from a similar experience (Driver and Bell, 1986). This accounts for the wide range of answers generated in this study. Cho et at. (1985) provided a further explanation for this variation. They believed that the pupils' preconceived ideas influenced the way in which they related to the new information presented during tuition. The 'Bur' model (Schaefer, 1979) provides a possible explanation of how this comes about. Inappropriate associations may be hooked onto the various concepts which in turn prevent the attachment of more suitable associations, such as linking colour to genetics exercises described above.

The two-tier multiple choice questionnaire used in this study was entirely compiled of misconceptions held by standard 10 pupils, some of which could have arisen from these inappropriate associations. It was interesting to note that in some cases a misconception that had been chosen by only one pupil during the pilot test, was a popular choice in the actual study. This could have been due to a word or phrase triggering off an association which had not been intended. Question 7 is a perfect example.

**MISCONCEPTIONS**

A comparison of the ideas held by the three groups of respondents identified some misconceptions which were long-standing and others which were less so.

The standard 8 group were not aware that physical damage to a plant cannot be inherited. This shows an inability to distinguish between healing a wound and producing seeds. The contribution of genes as opposed to the reproductive organs is not obvious to pupils. The results of this study show that this problem can be clarified by further tuition, however. This misconception could also be linked to an inadequate understanding of sexual reproduction, although this study shows that despite further tuition, plants are still seen to be unable to reproduce sexually by some of the respondents. This is consistent with the findings of Okeke and Wood-Robinson (1980).

The inheritance of characteristics is adequately understood by all three groups but the standard 8 pupils are unable to relate this to sexual reproduction. This problem is resolved in some cases after further tuition but a large percentage of students are still unable to comprehend the relationship.

The standard 10 and first year university groups' understanding of genetics was examined in questions 5 to 9. This revealed that some misconceptions present in standard 10 can be clarified by further tuition. These include the fact that every cell in the body contains a complete set of genes, every chromosome has a partner which it received from the opposite sex parent and that a recessive characterisic can only be inherited if the offspring receives the gene from both its parents. However, other misconceptions prevail despite the additional tuition. These include an inability to understand the processes underlying a Punnett diagram, an inability to link Mendel's law of segregation to the movement of chromosomes during meiosis and an inability to comprehend the role of chance in genetics. The first is consistent with the findings of Stewart and Dale (1981), Stewart (1982) and Moll and Allen (1987), the second with those of Stewart and Dale (1981), Longden (1982), Stewart (1982) and Moll and Allen (1987) while the third is consistent with the findings of Deadman and Kelly (1978), Kargbo et al. (1980) and Hackling and Treagust (1984).

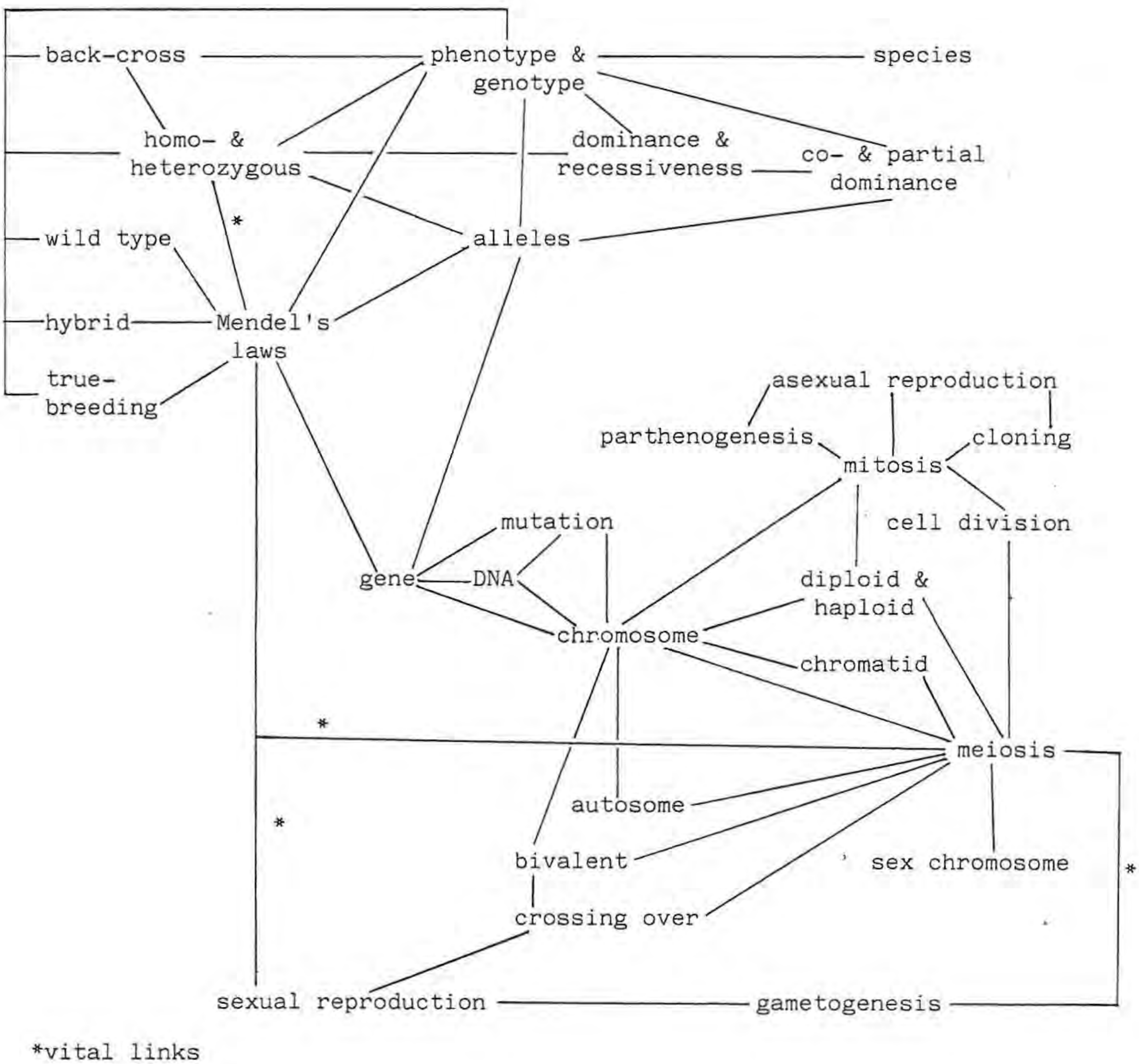
**POSSIBLE REASONS FOR THE MISCONCEPTIONS**

Carey's study (1985) of conceptual development in children provides a possible explanation for the misconception regarding plants and sexual reproduction. She found that people are used as the prototype with which other objects are compared. The more similar the object is to people, the more likely they are to share characteristics. Plants, having very little similarity to people are, consequently, less likely to have perceived 'human' characteristics. Sexual reproduction may be understood in people but not be projected to plants. Although this theory was based on children under ten years of age, it could quite possibly be used in this situation. Afterall, a few responses to question 3.2 showed a naturalistic conceptual framework (Kargbo et al., 1980) which is characteristic of children under ten, even though they had shown a genetic framework in the previous question. This suggests a possible regression in certain circumstances.

This problem with plants could also account for many of the problems in genetics as the standard 9 course starts with Mendel's work and continues with the work of Correns, both of whom worked primarily with plants. If children are unlikely to relate characteristics of people to plants, they are even less likely to project plant processes to people.

The term, intergrative reconciliation, coined by Ausubel (1968, in Novak, 1978) provides an explanation of how this projection should occur. New information should be able to link together concepts that were previously seen as different and unrelated. The results of this study, however, show that this does not always happen, for example plants are seen to reproduce differently to animals and people, and genetics is seen to be unrelated to meiosis. For this linkage to occur, superordinate learning must take place whereby new information helps to link concepts together, giving them new meaning in the process. In this way a suitable conceptual framework can be built up that will link the various concepts together rather than leave them isolated and unrelated to each other. An example of such a framework is depicted in figure 2. It is obvious from this study that certain of the connecting links in this map are absent from many of the respondents' conceptual frameworks. The most obvious ones are marked with an *. These missing links explain the steadfastness of the misconceptions concerning the segregation of alleles and meiosis, and the processes underlying a Punnett diagram.

FIGURE 2: Concept map of senior secondary school genetics (adapted from Pearson and Hughes, 1986)




*vital links

Tied up with these linkage problems could be the problem of terminology such as confusing chromosomes and chromatids. A term cannot be fully understood unless it is fitted into the conceptual framework. Understanding the term recessive, for example, relies on the realisation that both parents have to have the gene. This fact cannot be part of the conceptual framework if the pupil is unclear as to the genetic contribution of the parents. This highlights the problem one misconception can have on the acquistion of new information.

Cho et al. (1985) believed that as the textbook is one of the major sources of information, it could also be the source of the misconceptions. The misconception concerning chance could have originated in this way in that some textbooks emphasise phenotypic ratios. The results of questions 7 and 9.3 show that some of the respondents are influenced by ratios so this could be true. Furthermore some of the genetics questions are phrased in such a way that the offspring are seen as certainties. This is inadvisable as children feel most comfortable with certainties and tend to avoid explanations that deal with probabilities (Deadman and Kelly, 1978). If the textbook encourages this tendency, the aspect of chance will never be considered. A discussion of the various textbooks available in the Cape Province is included in chapter 7.

**PUPILS' CONCEPTIONS OF THE PROBLEM**

The results of the final question in the pilot questionnaire show that the pupils are aware of many of the problems discussed above.

Terminology was listed by many of the pupils as a problem. Terms such as homozygous, heterozygous, dominant, recessive and genotype were the commonly listed examples. A specific example was distinguishing between a gene and a gamete. Added to this are the symbols used in genetics which were also listed as a problem area. Genetics is characterised by its very specialised vocabulary and it is not surprising that pupils find it difficult to become familiar with the vocabulary and grasp the underlying concept at the same time.

"The whole concept of genetics" was also listed as a problem which proves that pupils do find it difficult to relate to the subject as it is too abstract. This was the reason given by Driver and Bell (1986) for poor attainment in classroom science. It could also be a problem in that it results in the 'two- world perspective' proposed by Osborne and Wittrock (1985) which compartmentalizes school science and everyday science. Genetics would fall into the school category and as such would be unrelated to everyday life. A question which was not taken directly from the school work would therefore not be answered using work learnt in class but by preconceived ideas held by the child concerning everyday life. This could result in incorrect answers and a distorted view of the real world.

The type of questions asked were also listed as problems. 'Family tree' problems (such as question 9) and applying Mendel's laws were mentioned but the most common problem appeared to be questions asking for an explanation of how the offspring were determined other than by using a Punnett square. This shows a lack of understanding of the underlying processes. This has been substantiated by theorists (Stewart and Dale, 1981; Stewart, 1982; Moll and Allen, 1987) who have found that the use of the Punnett square algorithm is successful in solving problems in a non-meaningful way only, as the pupils carry out the required steps without knowing why they are doing them.

So it can be seen that certain problem areas have been identified, some of which were also recognised by the pupils. The solution appears to lie with the teacher who can adopt suitable teaching strategies in an attempt to rectify the problems. The way this can be done will be discussed in chapter 7.

# CHAPTER 7

# IMPLICATIONS

## INTRODUCTION

As most of the problems discussed in this study hinge on the pupils' preconceived ideas, it is imperative that the teacher be aware of these ideas and structure the lessons accordingly. Once the teacher has identified these ideas through discussion or test questions, he or she should challenge these ideas and, hopefully, overthrow them. This can be done by providing sufficient 'fuel' in the form of discussions and factual evidence, to convince the pupils that their everyday explanations are unsuitable. Clough and Wood-Robinson (1985) stress the importance of incorporating ideas from everyday experience so that the pupils get the opportunity to question their opinions. This study has identified some long-standing misconceptions that need special attention as they hinder further learning. The implications of this are discussed below.

## SEXUAL REPRODUCTION

The fact that plants are thought to be unable to reproduce sexually is a major problem area. This problem is complicated by the tendency to transfer characteristics from man to animals but seldom to plants as described by Carey (1985). It is also a debatable point whether pupils transfer processes involving plants to animals as is expected in genetics. However, the latter point will be discussed later.

Very little work has been done on the former problem so it is difficult to suggest ways to overcome it. It appears that the problem lies in an inadequate understanding of sexual reproduction. It is imperative that pupils be made aware from the first time sexual reproduction is taught in school, that it involves the fusion of an egg cell from the female individual and a sperm cell from the male. This should then be explained using a variety of examples including plants, invertebrates and mammals. This should be the trend for all the courses involving sexual reproduction at least from the junior secondary stage.

Terminology also needs to be considered when drawing up these courses especially in the courses concerning the reproduction of plants. In the lower plants for instance, there are various terms for the sperm cell such as spermatozoid, spermatozoon and antherozoid, which are confusing to the pupil. It is suggested that in a situation such as this, understanding the process is preferable to remembering the finer points of the associated terminology. Using either 'male gamete' or 'sperm cell' in all of the life cycles should be sufficient so that all the life cycles are comparable, even the more complicated ones of the spermatophytes. This should also be true for the animals that are studied. Terminology should be based on the following core concepts:

1. Egg cells (not merely eggs to limit confusion with a bird's egg) or female gametes are produced in a female sex organ.
2. Sperm cells or male gametes are produced in a male sex organ.

3. Sperm cells are transferred to the female in some way.

4. One sperm cell fuses with one egg cell to form a zygote.

With those four points as the framework, sexual reproduction should be easier to understand as the different examples can be examined as variations rather than different processes.

Simple genetics can be introduced to the pupils during these courses on sexual reproduction so that the pupils become aware that the two subjects are linked. This need not be very technical but can be done by discussing situations with which the pupils are familiar such as their pets, as suggested by Clough and Wood-Robinson (1985). Here again plants should be brought in if possible - perhaps by discussing examples of crops or flowers in the area or of which they are aware. If this is done from standard 6 onwards, by the time the pupils reach standard 9 they should be aware that sexual reproduction and genetics are related which will facilitate the development of suitable conceptual frameworks. It is felt that the standard 8 course lends itself to a short course on cell division and genetics. It has been found that both these sections can be fitted into the year without jeopardising any other section and it ensures that the ground work has been laid for the standard 9 course. The pupils have the opportunity to work through some of the concepts involved and identify areas of difficulty and in this way it is felt that they derive more benefit from the standard 9 course. This should be investigated on a wider scale, however, to determine whether or not it is actually advantageous.

Returning to the fact that pupils may not equate plant processes to animals mentioned earlier, leads one to a problem with the present standard 9 genetics course which deals almost exclusively with plants.

The teacher should, therefore, relate the theories to as many human and animal examples as possible in an attempt to get the pupils to relate the processes to **all** living organisms. It should also be noted that ideally the examples should de-emphasise ratios to minimise the problem of comprehending the 'law of large numbers' isolated by Hackling and Treagust (1984) as well as colour which was found to be seen as a significant factor by the pupils in this study.

## CHANCE

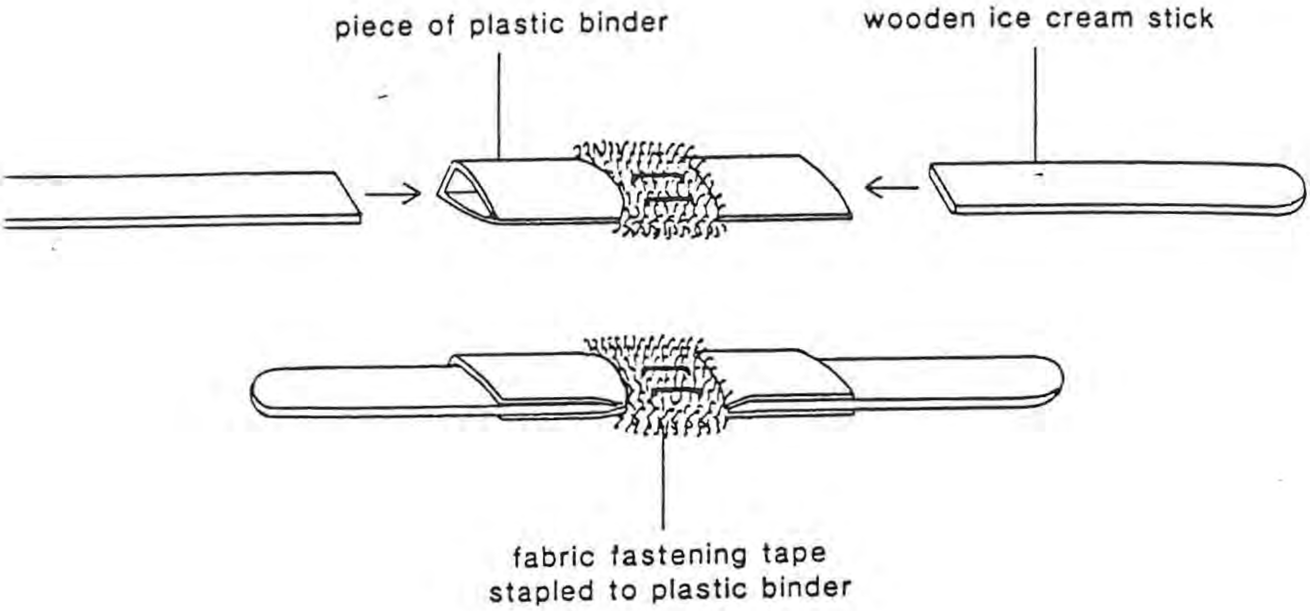
To make the pupils aware of the influence of chance, practical examples need to be carried out. Actual breeding experiments are difficult to carry out in the classroom as they are time-consuming. It has been suggested that computer simulations provide a suitable alternative (Shone, 1980). On examining an example of such a program, one questions the reality of the situation, however. It is still very much a paper and pencil type of exercise. There is also the problem of side issues, such as those involved in using a computer, causing confusion (Dean and Murphy, 1973). Furthermore, as computers are not freely available they do not represent a universal solution.

A useful exercise to illustrate the concept of chance which can be used in any classroom, is that of sex determination. In a mixed class, two 'bags of gametes' need to be made, one containing the female sex chromosomes and the other those of the male. The pupils are first involved in filling these bags, with each pupil writing one of each of his or her sex chromosomes on pieces of paper. The boys will therefore contribute equal numbers of pieces of paper bearing either an X or a Y.

The girls will contribute only X's. In this way, the pupils become aware of the segregation of chromosomes during gametogenesis as well as the correlation between sex chromosomes and gametes. The latter can be emphasised by cutting the paper to resemble either an egg or a sperm cell. Once the bags have been filled, each pupil will take an egg and a sperm cell from each bag to determine the sex of his or her 'child'. These are noted on the board and once every pupil has a 'child', the ratio is calculated which may or may not correspond to the expected ratio. This exercise will work equally well with mono- and dihybrid crosses. Hopefully the expected ratios will not always be found which will show the pupils that chance plays an integral part in genetics.

This exercise can also be carried out using models of a chromosome such as one made from two strands of 'poppit' beads (each bead has a socket at one end and a peg at the other) held together by a pipe-cleaner. Heath (1975) used these beads to build a DNA strand as well. This type of model has been found to be ideal to describe the movement of chromosomes during mitosis and meiosis, to show swopping of genetic information and, by labelling a bead as a gene, they can be used in genetics exercises. Unfortunately, they are no longer freely available. However, the model described by Taylor (1988) made of suckersticks, pieces of plastic binder and fabric fastening tape (figure 3), could be a suitable substitute. They will take longer to make, individual 'genes' cannot be swopped and they cannot be shaped to resemble the chromosomes during the different stages of cell division, but they will still be invaluable to relate meiosis to Mendel's work - a link often missing from the pupils' conceptual frameworks (figure 2).Other models have been suggested such as the linkage clock (Kemp, 1971) and the heredíscope (Branford Oltenacu, 1983) but they are not as multi-purpose as the chromosome models described above. The heredisope, however, could be linked to the chromosome model to determine the combination of genes so that chance can be stresssed during the exercise as well.

FIGURE 3: Chromosome model (Taylor, 1988, p 510)




MEIOSIS/GENETICS

Many of the problems isolated in this study could have stemmed from an inability to see how meiosis, sexual reproduction and genetics are inter-linked. This is compounded by the fact that most of the available textbooks (Du Toit et al., 1986; Thienel et al., 1986; Smit et al., 1988) deal with these processes in separate unrelated chapters as found by Cho et al. (1985) in their study of Korean textbooks. One textbook (Claassen et al., 1986) includes the role of the nucleus, cell division and genetics in a chapter entitled 'the continuity of life'.

Unfortunately, human reproduction is not included in this chapter. Gametogenesis is described under meiosis, however, so the link is made nonetheless and is very clearly illustrated in diagrams that relate the stages of cell division to gamete production (Claassen et al., 1986, p 305).

It is imperative that the teacher stress these links as they are not obvious to all the pupils. This can be done by using a chromosome model as described above or the "genes-on-chromosome" model described by Hackling and Treagust (1984) in which the letters normally used in genetics exercises are drawn on chromatids. It would seem that this approach would be the ideal starting point for Mendelian genetics as it illustrates the concept of genes being found on chromosomes in each gamete as well as highlighting the significance of the haploid and diploid number of chromosomes. The model can be elaborated to explain the movement of chromosomes during meiosis and so help the pupils understand gamete formation during dihybrid crosses. This model can also be adapted so that cut-outs of chromosomes with the genes written on them can be used on the overhead projector to explain the process to the whole class. Similarly, cut-outs or models can be used for group work. The whole aim being to give the pupils as much opportunity as possible to work through the concepts of meiosis, gametogenesis and fertilisation so that the links depicted in figure 1 can be made.
In the analysis of textbooks by Cho et al. (1985), it was found that chromosomal division, allelic segregation and independent gene assortment were discussed separately and not related in any way which could cause the misconception discussed above. Textbooks avaiable in the Cape Province do not all have this problem. Claassens et al. (1986) present these three processes under separate sections but they are

related in the text. The strong point of this text is that the processes are used to explain Mendel's monohybrid crosses. This should help the pupils' superordinate learning. In addition, the diagram depicting independent assortment on page 349 is very clear.

Thienel et al. (1986) do not make these links. There are no diagrams and the only mention made to meiosis is a short paragraph on page 297 of the genetics chapter asking the pupil to refer back to the chapter on meiosis. Du Toit et al. (1986) does include a diagram on page 198 to explain Mendel's experiment. However, it is confusing in that the parents have two chromatids (not chromosomes) making up each bivalent. Furthermore, the diagram does not make obvious links to meiosis and neither does the explanation on page 199. Independent assortment as a separate section is omitted and it is briefly mentioned under the heading dihybrid crosses. Consequently very few links joining the three processes are made explicit. Smit et al. (1988) is better in that they include a clear diagram under the section on independent assortment on page 382 which does attempt to link the three processes together. However, it would have been better had a similar diagram been included under Mendel's work as Claassens et al. (1986) do, as that is where the different processes are first discussed.

The order in which the work is taught is another factor of which teachers should be aware. It has been suggested (Cho et al., 1985) that the sequence should be genetics/meiosis/chromosome theory. However, meiosis itself is a complicated process which is best dealt with separately so that a basic understanding can be obtained before the complicated terminology involved in genetics is introduced. Here again the advantage of teaching cell structure and cell division together in standard 8 is evident.

The teacher should also be aware of other shortcomings in the available textbooks. Only one of the problems identified by Cho et al. (1985) is not evident in these textbooks namely the relationship between homozygous/heterozygous and dominant/recessive. The relationship between terms such as allele, gene, DNA, chromosomes, trait and zygote as well as suitable definitions are not quite as clear in all the textbooks, however. Smit et al. (1988) provided the most complicated definitions which could possibly hamper the pupils' understanding of the concepts. Du Toit et al. (1986) is better in that all of the definitions are clear except that of an allele. Both Thienel et al. (1986) and Claassens et al. (1986) provide fairly clear definitions and relationships. There are slight variations between the definitions of the different terms but these need not necessarily be a source of confusion as suggested by Cho et al. (1985). Instead they could be used as source material for group discussions and in this way the pupils are able to develop their 'burrs' of the various concepts. Finally, the fact that replication is not seen as the process which produces two chromatids for each chromosome is not mentioned in any of the textbooks. This fact could be an important link in the understanding of genetics and meiosis.

An associated problem that became evident from the responses to question 5 is that the zygote is seen to be unrelated to body cells. Once the pupils can see the links between meiosis and genetics, they may find it easier to understand that each cell has a complete set of genes and so link meiosis, sexual reproduction and mitosis together. A useful way to explain this is to use the example of cloning. Unfortunately there are no similar animal or human examples which can be used to substantiate this.

**PUNNETT SQUARE**

The types of exercises given to the class need to be chosen so that they test whether these links have been made. Allen and Moll (1986) list ten questions which can be used to do this. When answering these questions, the pupils are encouraged to explain their answers using diagrams of chromosomes which will not only give feedback of each pupil's line of reasoning, but will do away with the dependence on the Punnett square which should not be introduced until the pupils understand the processes involved in genetics. Collins and Stewart (1989) suggest the use of an expression chart to avoid using the Punnett square, but as this is merely a list of all possible crosses and offspring, it does not provide the pupils with cytological reasons for what is occurring and is of limited value.

It must be mentioned that questions such as question 6 which is similar to those of Allen and Moll (1986), use stylised diagrams which are simplified to make the point. Where possible these should be related to photomicrographs of actual sets of chromosomes such as those in Claassens et al. (1986, pp 368 & 387). This will test the pupils' ability to relate the process to the actual situation which is more complex. This is a simple, but accurate means of checking the pupils' understanding. It also limits the confusion mentioned by Cho et al. (1985), which the various diagrams used in biology textbooks can evoke.

Genetics exercises should always be as meaningful as possible to keep the pupils' interest and encourage learning. Haddow et al. (1988) suggest that exercises concerning human genetics should be included as pupils "will certainly be faced with making decisions in matters involving genetics in relation to personal and public health" (Haddow et al., 1988, p 496). Questions such as these will not only educate the pupils in aspects of human genetics but will help to explain concepts such as dominance and chance. Question 3 in this study shows that pupils relate well to questions concerning humans so including such questions can only be to the good. These could include such phenomena as cystic fibrosis (Haddow et al., 1985), Down's syndrome (Smit et al. 1988), sickle cell anaemia, tongue rolling (Claassens et al., 1986) and brachydactyly (very short fingers) which was one of the first studies of single gene inheritance in man (Jones and Karp, 1986).

Finally, the fact that the subject matter in genetics is abstract, possibly tentative in some areas and bound up in a vocabulary all of its own must be mentioned. As an introduction to the course, a brief history of the ways in which the theories developed such as that put forward by Louw (1989), could give the pupils some insight into the tentative nature of the subject. Corcos and Monaghan (1987) suggest that a historical perspective is important as it shows pupils that scientific advance is not a smooth logical process. The fact that some of terms such as 'gene' (Evans, 1981) cannot be defined precisely, is a further complication compounded by certain textbooks as previously discussed. The teacher therefore has to select suitable definitions that will fit in with the work to be covered. The complexity will depend on the ability of the class. For instance, a superstream class may benefit by the inclusion of such concepts as DNA ligase as suggested by Cochrane and Dockerty (1984), but a weaker class will merely be swamped by the additional terminology required to understand the concept.

The onus therefore is on the the teacher to provide suitable definitions and allow the pupils to work with them so that inconsistencies such as the chromosome/chromatid problem evident in this study, can be eradicated. The emphasis here is on working through the content so that the pupils can develop a "wider view of science as a method of reasoning and studying the unknown" (Brumby, 1984, p 501) rather than learning by rote a body of 'facts' which in the case of genetics may not even be facts, so that they can 'know' the correct answers. As Brumby (1979; 1984) found, the latter is not the way to prevent misconceptions.

# CHAPTER 8

## CONCLUSION

The aim of this study was to identify commonly held misconceptions in secondary school genetics. Misconceptions identified in a free response questionnaire were used to compile a two tier multiple choice questionnaire. Certain of these misconceptions were found to be held by respondents in all of the three groups studied. This implies that the misconceptions were unaffected by age or further education. Four misconceptions were seen to be basic to the problem. These involved the following:

1. Plants being unable to reproduce sexually.
2. An inability to relate meiosis and genetics.
3. Use of the Punnett square algorithm without understanding the underlying processes involved.
4. An inability to recognise the aspect of chance involved in genetics.

These misconceptions were seen to have arisen because of preconceived ideas hampering the formation of a suitable conceptual framework. In addition, terminology was seen to be a problem which further complicates the issue.

Arising from this study, it appears that a detailed analysis of pupils' ideas regarding sexual reproduction needs to be done so that the problem with plant reproduction as well as the inability to form suitable links between meiosis and genetics can be investigated.

Many of the misconceptions identified in this study can be avoided if the teacher challenges the pupils' preconceived ideas by explaining the various concepts using many and varied examples familiar or of interest to the pupils. Genetics, cell division and meiosis should be taught as a unit and the three areas related wherever possible. This can be done using models, activities and suitable meaningful examples. The problem of terminology can be avoided by providing suitable definitions which can be used and tested by the pupils so that they can work through them and eventually accept them. The emphasis should not be on rote learning but on reasoning and working with the information available.

The curriculum designer needs to consider when sexual reproduction is first introduced to the child and to ensure that a variety of organisms are included as examples. The terminology needs to be simplified so that the same core concepts are used in all of the courses dealing with sexual reproduction. Studies need to be conducted to ascertain the feasibility of including a short course on genetics and cell division in standard 8.

As a pilot, this study identified misconceptions held by South African pupils which had previously been isolated by researchers in other countries. Various ways have been suggested to avoid these problems but further research is needed to ascertain which of these strategies will be successful.

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## QUESTIONNAIRE ON GENETICS

*Research is being done in the field of genetics as taught in high schools in South Africa and it would be most helpful if you would complete this questionnaire. Please try to answer all the questions especially the sections asking for reasons.*

| ANSWER ALL THE QUESTIONS IN THE SPACES PROVIDED |
|---|

1. If a tree is wounded and it heals its wound, would the scar formed be transferred to the seedling of this tree? Explain your answer.

2. If the leaves of a plant are continually cut in half, will the plant eventually grow leaves that are shaped like the two halves instead of one whole leaf? Explain your answer.

3.1 If a tall man and a short woman have a son, how tall will he be when he is fully grown? Give a reason for your answer.

3.2 If the child is a girl, how tall will she be? Give a reason for your answer.

3.3 Do you know of any other things which could make a child grow taller?

Explain how your answer above makes the child grow taller.

4.1 A mouse born with no tail was mated with a normal tailed mouse. One mouse was born without a tail - how might that have come about?

4.2 Can you explain why the litter contained some babies with tails and some without?

____________________________________________

____________________________________________

5. State whether the following is true or false: sperm carries genes for half the features found in the offspring. ________

Give a reason for your answer: ____________________________

____________________________________________

6. What is the percentage chance of a baby born of two hybrid parents having the dominant trait? Explain your answer but do NOT do so using a diagram.

____________________________________________

____________________________________________

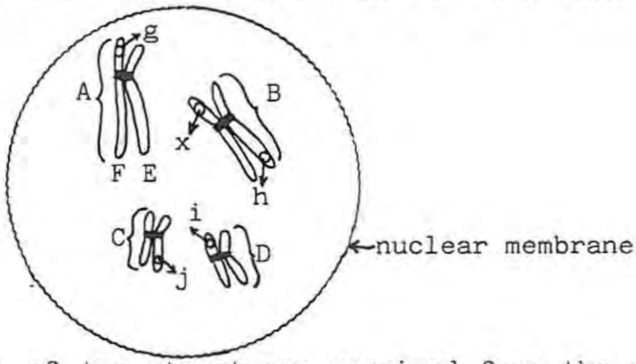
____________________________________________

7. Different cell types (skin, muscle, blood etc.) found in a person's body contain . . . . . . . . . . . . . sets of genes as the zygote.
Explain why you filled in the word(s) you did above:

____________________________________________

____________________________________________

8. The diagram below represents four chromosomes in the nucleus of an organism's cell.




8.1 Write down the letters of two structures received from the organism's father. ____________

Explain your choice: ______________________________

____________________________________________

8.2 Write down the letters of a homologous pair of chromosomes. ________

Why did you choose those two? ____________________________

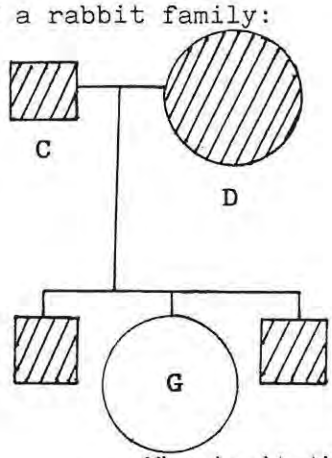
____________________________________________

8.3 If X represents the gene for blue eyes, where would you expect to find its allele? Explain your answer.

______________________________________________

______________________________________________

9. The diagram below shows the pedigree of a rabbit family:




*KEY:*

*squares = males*
*circles = females*

*shaded symbols = black fur*
*unshaded symbols = white fur*

*white fur is* ***recessive***

9.1 What is the genotype of G? ______________ Why is it that genotype?

______________________________________________

9.2 What does the genotype of G tell you about the genotype of C and D? Explain fully.

______________________________________________

______________________________________________

______________________________________________

10. The letter B represents the dominant gene for black colour in beetles, b the recessive gene for red colour. A red beetle is crossed with a homozygous black beetle. If a Punnett square is used to determine the offspring it would look like this:

| | v | w |
|---|---|---|
| x | z | |
| y | | |

10.1 What letters would you place in squares v, w, x and y and why would you do it like that?

______________________________________________

______________________________________________

______________________________________________

10.2 What would be the genotype of the offspring marked z? ________

How did you arrive at this answer? ______________________

______________________________________________

______________________________________________

11. The genotype for a certain characteristic is Tt. Indicate how the genes will be distributed in each of the four sex cells after the process of meiosis.

Explain how you arrived at your answer.

12. Seed obtained from a self-pollinated tall plant produced one relatively short plant. How do you explain this?

13. When is Mendel's law of segregation applicable? Explain.

14. What do **you** find most difficult about genetics?

*Thank you for your co-operation.*

# WHAT DO YOU KNOW ABOUT GENETICS?

## INSTRUCTIONS

Answer all the questions on the answer sheet provided.

Before you start, it is important that you fill in your **class**, **age** and **sex**. Filling in your name is optional.

Each question has two parts: a multiple choice **answer** and a multiple choice reason for that answer. *Please ensure that **BOTH** choices are filled in.* If you have another reason, fill in [e] in the 'reason' box and then write your reason in the space provided. DO NOT WRITE IN THE 'CODE' BOX.

**USE THE FOLLOWING STEPS WHEN ANSWERING EACH QUESTION:**

1. Read the question **carefully** before attempting to answer it.

2. Choose the most suitable answer and record the relevant **number** in the box on your answer sheet.

   eg. 1. [2] Reason [ ]

3. Read the reasons carefully and then choose the one that best suits the way you thought out the answer. Record the relevant **letter** in the 'reason' box.

   eg. 1. [2] Reason [a]

   *Remember to fill in **your reason** if you choose* [e]

4. If you change your mind, cross out the incorrect answer and write the new answer next to it.

   eg. 1. [2] Reason [~~a~~] b

1. If a tree is wounded and it heals its wound, how would the scar affect the seedling of this tree?

    1. It would not affect the seedling if the scar heals before the seeds are formed.
    2. The seedling would be scarred.
    3. The seedling would not be affected.
    4. The seedling would only be affected if the scar was very deep.

REASON

(a) The seedling inherits ALL the characteristics of the tree.

(b) A deep wound will affect the cells and consequently the seedling.

(c) Bark is not involved in reproduction so the seeds will not be affected.

(d) The characteristics of the scar are not encoded in the genetic make-up.

(e) ______________________________

2. If the leaves of a plant are continually cut in half lengthwise, what will eventually happen to the new leaves produced by that plant?

    1. The new leaves will be shaped like the two halves instead of the whole leaf.
    2. A mutation will occur.
    3. The shape of the new leaves will be unaffected.
    4. The leaves will be narrower.

REASON

(a) The number of chromosomes will be halved each time the leaf is cut.

(b) The genotype is not affected as damage done to the plant is not inherited.

(c) The tree adapts itself to the new situation.

(d) The genes that influence the shape of the leaves are damaged.

(e) ______________________________

3.1 If a tall man and a short woman have a son, how tall will he be?

    1. As tall as his father.
    2. Short like his mother.
    3. Of medium height.
    4. Any height from tall to short.

REASON

(a) Tall is dominant over short.

(b) His height will depend on the genes he inherits from his parents.

(c) He is a boy so he has the same genes as his father.

(d) He has half his father's tall genes and half his mother's short genes, so he will be of medium height.

(e) ______________________________

3.2 If their child is a girl, how tall will she be?

1. As tall as the son.
2. Of medium height.
3. The same height as the mother.
4. Any height from tall to short.

REASON

(a) She is a girl with XX sex chromosomes so she will inherit her mother's characteristics.

(b) The genes inherited from both parents determine the child's height.

(c) Females are characteristically shorter than males.

(d) The father's genotype is dominant.

(e) ______________________________

3.3 Do you know of any other things that could make a child grow taller?

1. Growth hormones.
2. Stretching exercises.
3. A diet high in protein foods.
4. Steroids.

REASON

(a) Hormones regulate the metabolism of the body.

(b) Proteins enable growth to occur.

(c) The more one eats, the taller one grows.

(d) Muscle growth is increased making the child bigger.

(e) ______________________________

4. When compared to a zygote, different cell types (skin, muscle, bone, etc.) contain . . . . . genes as the zygote.

1. the same
2. different
3. homologous
4. twice as many

REASON

(a) Only the zygote has a diploid number of chromosomes; after meiosis the number becomes haploid.

(b) The zygote receives one set of genes from each parent.

(c) The zygote contains all the genes needed to form a new individual.

(d) Genes contained in different cell types are all different.

(e) ______________________________

5. The statement "sperm carries genes for half the features found in the offspring" is ...

1. true
2. false

REASON

(a) Sperm carries one or more genes for every feature found in the offspring.

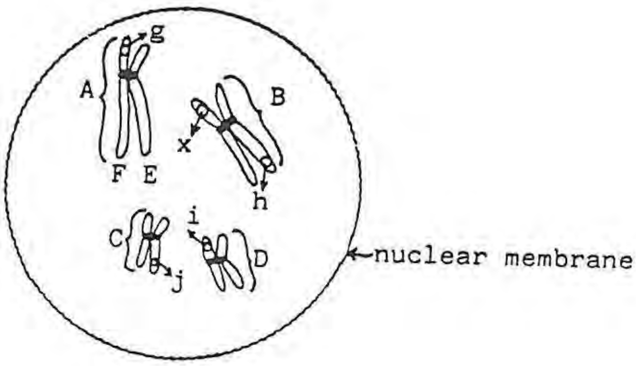
(b) Genes are split up when sperm is formed.

(c) A sperm and an ovum fuse therefore the offspring receives half of its genes from its mother and the other half from its father.

(d) Meiosis halves the number of chromosomes to form haploid sperm cells

(e) ______________________________

6. The diagram below represents four chromosomes in the nucleus of an organism's cell.




6.1 The following two structures were received from the organism's father:

1. A and B
2. A and D
3. i and j
4. C and D

REASON

(a) The father's sperm is smaller than the ovum.

(b) One chromosome from each bivalent is found in the sperm cell.

(c) The bigger chromosomes come from the father.

(d) They are homologous chromosomes so they can exchange genetic material.

(e) ______________________________

6.2 The following two structures represent a homologous pair of chromosomes:

1. A and B
2. F and E
3. A and D
4. g and x

REASON

(a) They share the same characterisitics.

(b) They are found close to each other.

(c) They are similar in size and shape.

(d) They lie next to each other, become attached at the chiasma and exchange genetic material.

(e) ______________________________

6.3 If x represents the gene for blue eyes, its allele would be found at ...

1. g
2. h
3. i
4. F

REASON

(a) Alleles are found on a corresponding site on the other chromosome of the bivalent.

(b) Alleles are found on chromosomes of the genes.

(c) Alleles are found on the opposite side of the chromosome.

(d) Alleles are found on the same sets of chromosomes.

(e) ______________________________

7. The genotype for a certain characteristic if Tt. How will the genes be distributed in each of the four sex cells produced by meiosis?

1. TT Tt Tt tt
2. Tt Tt
3. T T t t
4. 3 dominant to 1 recessive (ratio 3:1)

REASON

(a) The number of chromosomes is doubled, each gene divides once and then in half so that there are 4 single gene, one in each gamete

(b) The answer can be reached by taking each letter out of the parent formula.

(c) By using a diagram to cross the genes.

(d) The genes are separated into two cells, one with T and the other t which then form another sex cell during the second meiotic division.

(e) ______________________________

8. With what process is Mendel's law of segregation directly associated?

   1. Meiosis
   2. Crossing over
   3. Colour determination
   4. Determination of genotypes

REASON

(a) A plant wih red flowers is crossed with one with white flowers to produce one with pink flowers.

(b) It explains how gametes are crossed.

(c) When cross fertilisation occurs it shows what type of offspring will occur.

(d) During the production of sex cells, genes on bivalent chromosomes are separated from each other.

(e) ______________________________

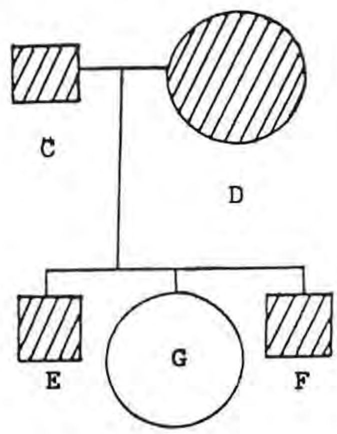
9. The diagram below shows the pedigree of a rabbit family:

*KEY:*

*squares = males*
*circles = females*

*shaded symbols = black fur* (B)
*unshaded symbols = white fur* (b)

*white fur is* ***recessive***




9.1 What is the genotype of G?

   1. BB
   2. Bb
   3. bb
   4. a white female

REASON

(a) G is female and g is a recessive gene.

(b) White is dominant over black in this rabbit.

(c) One of the parents had recessive genes.

(d) The gene for white fur is recessive so all white rabbits must be homozygous.

(e) ______________________________

9.2 What does the genotype of G tell you about the genotype of its parents: C and D?

1. They are both heterozygous.
2. They both have black fur.
3. One has recessive genes.
4. One is a male and one is a female.

REASON

(a) G was produced when a sperm cell fused with an egg cell.

(b) G is homozygous as it obtained one gene for white fur from its mother and the other from its father.

(c) Black fur is dominant.

(d) The parents are hybrids so they produced a hybrid offspring.

(e) ____________________

9.3 If E and F both have the genotype Bb, what will be the genotype of a fourth baby rabbit?

1. BB
2. bb
3. Bb
4. either BB, Bb or bb

REASON

(a) The parents are heterozygous so they will produce babies with the following genotypes: BB, Bb, Bb and bb.

(b) The parents are heterozygous black so they will produce 3 black babies for every one white one.

(c) There is a 75% chance of the babies being black, so the fourth baby will be black as there are only 2 black babies so far.

(d) Chance will determine the genotype of the offspring and there are three possibilities as both the eggs and the sperm carry either a white gene or a black gene.

(e) ____________________

*Thank you for your co-operation.*

**APPENDIX C**: Two-tier multiple choice questionnaire (test instrument)

# WHAT DO YOU KNOW ABOUT GENETICS?

## INSTRUCTIONS

Answer all the questions on the answer sheet provided.

Before you start, it is important that you fill in your **class**, **age** and **sex**. Filling in your name is optional.

Each question has two parts: a multiple choice **answer** and a multiple choice **reason** for that answer. *Please ensure that BOTH choices are filled in.* If you have another reason, fill in [e] in the 'reason' box and then write your reason in the space provided. DO NOT WRITE IN THE 'CODE' BOX.

**USE THE FOLLOWING STEPS WHEN ANSWERING EACH QUESTION:**

1. Read the question **carefully** before attempting to answer it.

2. Choose the most suitable answer and record the relevant **number** in the box on your answer sheet.

   eg. 1. [2] Reason [ ]

3. Read the reasons carefully and then choose the one that best suits the way you thought out the answer. Record the relevant **letter** in the 'reason' box.

   eg. 1. [2] Reason [a]

   *Remember to fill in **your reason** if you choose* [e]

4. If you change your mind, cross out the incorrect answer and write the new answer next to it.

   eg. 1. [2] Reason [~~a~~] b

1. If a tree is damaged and it heals its wound, how would the scar affect the seedling of this tree?

    1. It would not affect the seedling if the scar heals before the seeds are formed.
    2. The seedling would be scarred.
    3. The seedling would not be affected.
    4. The seedling would only be affected if the scar was very deep.

    REASON

    (a) The seedling inherits ALL the characteristics of the tree.

    (b) A deep wound will affect the cells and consequently the seedling.

    (c) Bark is not involved in reproduction so the seeds will not be affected.

    (d) The characteristics of the scar are not encoded in the genetic make-up.

    (e) ______________________________

2. If the leaves of a plant are continually cut in half lengthwise, what will eventually happen to the new leaves produced by that plant?

    1. The new leaves will be shaped like the two halves instead of the whole leaf.
    2. A mutation will occur.
    3. The shape of the new leaves will be unaffected.
    4. The leaves will be narrower.

    REASON

    (a) The number of chromosomes will be halved each time the leaf is cut.

    (b) The genotype is not affected as physical damage done to the plant is not inherited.

    (c) The tree adapts itself to the new situation.

    (d) The genes that influence the shape of the leaves are damaged.

    (e) ______________________________

3.1 If a tall man and a short woman have a son, how tall will he be?

1. As tall as his father.
2. Short like his mother.
3. Of medium height.
4. Any height from tall to short.

REASON

(a) Tall is dominant over short.

(b) His height will depend on the genes he inherits from his parents.

(c) He is a boy so he has the same genes as his father.

(d) He has half his father's tall genes and half his mother's short genes, so he will be of medium height.

(e) ______________________________

3.2 If their child is a girl, how tall will she be?

1. As tall as the son.
2. Of medium height.
3. The same height as the mother.
4. Any height from tall to short.

REASON

(a) She is a girl with XX sex chromosomes so she will inherit her mother's characteristics.

(b) The genes inherited from both parents determine the child's height.

(c) Females are characteristically shorter than males.

(d) The father's genotype is dominant.

(e) ______________________________________________

3.3 Do you know of any other things that could make a child grow taller?

1. Growth hormones.
2. Stretching exercises.
3. A diet high in protein foods.
4. Steroids.

REASON

(a) Hormones regulate the metabolism of the body.

(b) Proteins enable growth to occur.

(c) The more one eats, the taller one grows.

(d) Muscle growth is increased making the child bigger.

(e) ____________________________________

4. Sperm cells and egg cells contain chromosomes which carry 'instructions' (in the form of genes) necessary to 'build' a new individual. Is it true to say that a sperm cell carries **some** of these while the egg cell carries the remainder which are different to those of the sperm?

1. It <u>is</u> true.
2. It is <u>NOT</u> true.

REASON

(a) Sperm and egg cells each carry one or more genes for every feature in the new individual.

(b) Sperm and egg cells each contain half the number of chromosomes as body cells, so they each carry half the 'instructions' (genes) needed to produce a new individual.

(c) The new individual may have some of the mother's features and some of the father's, so the egg and sperm cells obviously carry different 'instructions' (genes).

(d) Sexual reproduction involves a sperm and an egg cell so the new individual must get half of its 'instructions' from the father and the rest from the mother.

(e) ______________________________________________

5. When compared to a zygote, different cell types (skin, muscle, bone, etc.) contain chromosomes carrying . . . . . genes as the zygote.

   1. the same
   2. different
   3. homologous
   4. twice as many

REASON

(a) Only the zygote has a diploid number of chromosomes; after meiosis the number becomes haploid.

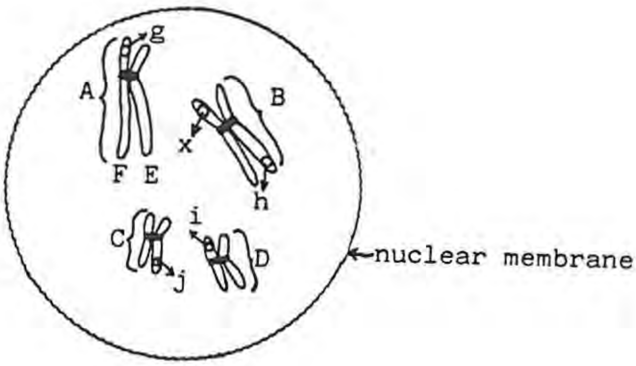
(b) Different cell types have different genes because they produce cells which differ in appearance.

(c) The zygote contains all the genes needed to form a new individual.

(d) The zygote is formed from an egg and a sperm cell so it has not got the same genes as skin cells etc.

(e) ______________________________

6. The diagram below represents four chromosomes in the nucleus of an organism's cell.




6.1 The following two structures were received from the organism's father:

   1. A and B
   2. A and D
   3. i and j
   4. C and D

REASON

(a) The father's sperm is smaller than the ovum.

(b) One chromosome from each bivalent is found in the sperm cell.

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(e) ______________________________

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1. A and B
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3. A and D
4. g and x

REASON

(a) They have identical genes.

(b) They are found close to each other.

(c) They are similar in size and shape.

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(e) ________________________________________

6.3 If x represents the gene for blue eyes, its allele would be found at ...

1. g
2. h
3. i
4. F

REASON

(a) Alleles are found on a corresponding site on the other chromosome of the bivalent.

(b) Alleles are found on chromosomes of the genes.

(c) Alleles are found on the opposite side of the chromosome.

(d) Alleles are found on the same sets of chromosomes.

(e) ________________________________________

7. The genotype for a certain characteristic is Tt. How will the genes be distributed in each of the four sex cells produced by meiosis?

1. TT Tt Tt tt
2. Tt Tt
3. T T t t
4. 3 dominant to 1 recessive (ratio 3:1)

REASON

(a) The number of chromosomes is doubled, each gene divides once and then in half so that there are 4 single gene, one in each gamete

(b) The answer can be reached by taking each letter out of the parent formula.

(c) By using a diagram to cross the genes.

(d) The genes are separated into two cells, one with T and the other t which then form another sex cell during the second meiotic division.

(e) ________________________________________

8. With what process is Mendel's law of segregation directly associated?

   1. Meiosis
   2. Crossing over
   3. Colour determination
   4. Determination of genotypes

REASON

(a) A plant wih red flowers is crossed with one with white flowers to produce one with pink flowers.

(b) It explains how gametes are crossed.

(c) When cross fertilisation occurs it shows what type of offspring will occur.

(d) During the production of sex cells, genes on bivalent chromosomes are separated from each other.

(e) ______________________________________________

9. The diagram below shows the pedigree of a rabbit family:

*KEY:*

*squares = males*
*circles = females*

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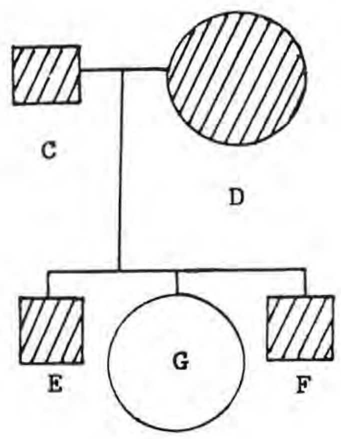
*white fur is* ***recessive***




9.1 What is the genotype of G?

   1. BB
   2. Bb
   3. bb
   4. a white female

REASON

(a) G is female and b is a recessive gene.

(b) White is dominant over black in this rabbit.

(c) One of the parents had recessive genes.

(d) The gene for white fur is recessive so all white rabbits must be homozygous.

(e) ______________________________________________

9.2 What does the genotype of G tell you about the genotype of its parents: C and D?

1. They are both heterozygous.
2. They both have black fur.
3. One has recessive genes.
4. One is a male and one is a female.

REASON

(a) G was produced when a sperm cell fused with an egg cell.

(b) G is homozygous as it obtained one gene for white fur from its mother and the other from its father.

(c) Black fur is dominant.

(d) The parents are hybrids so they produced a hybrid offspring.

(e) ______________________________

9.3 If E and F both have the genotype Bb, in reality what could be the genotype of a fourth baby rabbit?

1. BB
2. bb
3. Bb
4. either BB, Bb or bb

REASON

(a) The parents are heterozygous so they will always produce babies in the following genotypic sequence: BB, Bb, Bb and bb.

(b) The parents are heterozygous black so they will produce 3 black babies for every one white one.

(c) There is a 75% chance of the babies being black, so the fourth baby has to be black as there are only 2 black babies so far.

(d) Chance will determine the genotype of the offspring and there are three possibilities as both the eggs and the sperm carry either a white gene or a black gene.

(e) ______________________________

*Thank you for your co-operation.*

**APPENDIX D**: Answer sheet for standard 10 and first year groups

*WHAT DO YOU KNOW ABOUT GENETICS?*

# ANSWER SHEET

NAME: __ __ __ __ __ __ __ __ __ __ CLASS: _____

AGE: _____

MALE: ___ FEMALE: ___

* * * * * * * *

| QUESTION | | | | MY REASON | CODE |
|---|---|---|---|---|---|
| 1. | ☐ | Reason | ☐ | __________ | ☐ |
| 2. | ☐ | Reason | ☐ | __________ | ☐ |
| 3.1 | ☐ | Reason | ☐ | __________ | ☐ |
| 3.2 | ☐ | Reason | ☐ | __________ | ☐ |
| 3.3 | ☐ | Reason | ☐ | __________ | ☐ |
| 4. | ☐ | Reason | ☐ | __________ | ☐ |
| 5. | ☐ | Reason | ☐ | __________ | ☐ |
| 6.1 | ☐ | Reason | ☐ | __________ | ☐ |
| 6.2 | ☐ | Reason | ☐ | __________ | ☐ |
| 6.3 | ☐ | Reason | ☐ | __________ | ☐ |
| 7. | ☐ | Reason | ☐ | __________ | ☐ |
| 8. | ☐ | Reason | ☐ | __________ | ☐ |
| 9.1 | ☐ | Reason | ☐ | __________ | ☐ |
| 9.2 | ☐ | Reason | ☐ | __________ | ☐ |
| 9.3 | ☐ | Reason | ☐ | __________ | ☐ |

**APPENDIX E**: Answer sheet for standard 8 group

*WHAT DO YOU KNOW ABOUT GENETICS?*

## ANSWER SHEET

NAME: _ _ _ _ _ _ _ _ _ _

CLASS: _ _ _ _

AGE: _ _ _ _

MALE: ___ FEMALE: ___

* * * * * * * *

| QUESTION | | | | MY REASON | CODE |
|---|---|---|---|---|---|
| 1. | ☐ | Reason | ☐ | ____________________ | ☐ |
| 2. | ☐ | Reason | ☐ | ____________________ | ☐ |
| 3.1 | ☐ | Reason | ☐ | ____________________ | ☐ |
| 3.2 | ☐ | Reason | ☐ | ____________________ | ☐ |
| 3.3 | ☐ | Reason | ☐ | ____________________ | ☐ |
| 4. | ☐ | Reason | ☐ | ____________________ | ☐ |

**APPENDIX F:** Tables of responses expressed as the number of students responding to each answer option.

Standard 8: n = 110
Standard 10: n = 88
First Years: n = 52

## RESPONSES TO QUESTION 1

**GROUP:** Standard 8

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 3 | 7 | - | - |
| b | - | 1 | - | 21 |
| c | 5 | 1 | 27 | 2 |
| d | 4 | 2 | 32* | 2 |
| e | - | - | 1 | 1 |

**GROUP:** Standard 10

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | - | 3 | 2 | 1 |
| b | - | - | - | 6 |
| c | 4 | - | 26 | - |
| d | 2 | - | 39* | 1 |
| e | 1 | - | - | 1 |

**GROUP:** First year university level

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | - | - | 1 | - |
| b | - | - | - | 4 |
| c | - | - | 13 | - |
| d | 3 | - | 31* | - |
| e | - | - | - | - |

## RESPONSES TO QUESTION 2

**GROUP:** Standard 8

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 5 | - | - | 3 |
| b | - | 2 | 51* | 1 |
| c | 6 | 12 | 5 | 8 |
| d | 2 | 3 | 2 | 5 |
| e | - | 1 | 1 | 1 |

**GROUP:** Standard 10

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 1 | - | 1 | 3 |
| b | - | 2 | 56* | - |
| c | 2 | 7 | 1 | 7 |
| d | 1 | 1 | - | 1 |
| e | - | 1 | 1 | 1 |

**GROUP:** First year university level

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | - | - | - | - |
| b | - | - | 36* | - |
| c | 1 | 7 | 2 | 3 |
| d | - | 1 | - | 1 |
| e | - | - | 1 | - |

## RESPONSES TO QUESTION 3.1

**GROUP:** Standard 8

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 2 | - | - | - |
| b | 1 | - | 3 | 83* |
| c | - | - | - | - |
| d | - | - | 8 | 2 |
| e | - | - | 1 | 9 |

**GROUP:** Standard 10

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 6 | - | - | 1 |
| b | - | - | 1 | 71* |
| c | - | - | - | - |
| d | - | - | 5 | - |
| e | - | - | - | 4 |

**GROUP:** First year university level

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 1 | - | - | 1 |
| b | - | - | - | 47* |
| c | - | - | - | - |
| d | - | - | - | - |
| e | - | - | 1 | 2 |

## RESPONSES TO QUESTION 3.2

**GROUP:** Standard 8

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | - | - | 1 | - |
| b | - | 10 | - | 76* |
| c | - | 3 | 5 | 6 |
| d | 1 | 1 | - | - |
| e | - | - | - | 5 |

**GROUP:** Standard 10

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | - | - | 3 | 1 |
| b | 1 | 3 | 1 | 66* |
| c | - | 2 | 1 | 3 |
| d | 1 | - | - | - |
| e | 1 | - | - | 5 |

**GROUP:** First year university level

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | - | - | 1 | - |
| b | - | 3 | - | 43* |
| c | - | 2 | 2 | - |
| d | - | - | - | - |
| e | - | - | - | 1 |

RESPONSES TO QUESTION 3.3

**GROUP:** Standard 8

| REASON \ ANSWER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 70 | - | - | - |
| b | 2 | 1 | 12 | 1 |
| c | - | - | - | - |
| d | 5 | 2 | - | 6 |
| e | 9 | 1 | - | - |

**GROUP:** Standard 10

| REASON \ ANSWER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 64 | - | - | - |
| b | 2 | - | 2 | 1 |
| c | - | - | - | - |
| d | 5 | - | - | 5 |
| e | 9 | - | - | - |

**GROUP:** First year university level

| REASON \ ANSWER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 42 | - | - | - |
| b | - | - | - | - |
| c | - | - | - | - |
| d | 2 | - | - | 1 |
| e | 6 | - | - | - |

## RESPONSES TO QUESTION 4

**GROUP:** Standard 8

| REASON | ANSWER 1 | 2 |
|---|---|---|
| a | 5 | 5* |
| b | 24 | 13 |
| c | 42 | 13 |
| d | 4 | 1 |
| e | 1 | 1 |

**GROUP:** Standard 10

| REASON | ANSWER 1 | 2 |
|---|---|---|
| a | 2 | 12* |
| b | 7 | 19 |
| c | 23 | 9 |
| d | 7 | 3 |
| e | - | 5 |

**GROUP:** First year university level

| REASON | ANSWER 1 | 2 |
|---|---|---|
| a | 2 | 16* |
| b | 10 | 11 |
| c | 8 | - |
| d | - | 5 |
| e | - | - |

## RESPONSES TO QUESTION 5

**GROUP:** Standard 10

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 3 | 2 | 3 | 14 |
| b | - | 8 | 4 | - |
| c | 22* | 5 | 5 | 3 |
| d | 1 | 9 | 2 | - |
| e | 3 | 1 | - | 2 |

**GROUP:** First year university level

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 1 | - | - | - |
| b | - | 1 | - | - |
| c | 36* | 1 | - | 1 |
| d | - | 1 | - | 1 |
| e | 7 | - | - | - |

## RESPONSES TO QUESTION 6.1

**GROUP:** Standard 10

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 2 | - | 1 | 6 |
| b | 5 | 9* | 10 | 4 |
| c | 12 | - | - | - |
| d | 2 | 10 | 14 | 7 |
| e | 1 | - | 2 | - |

**GROUP:** First year university level

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | - | - | - | 1 |
| b | 2 | 19* | 6 | - |
| c | 5 | 1 | - | - |
| d | 2 | 3 | 5 | 1 |
| e | - | - | 2 | - |

## RESPONSES TO QUESTION 6.2

**GROUP:** Standard 10

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 11 | 4 | 3 | 6 |
| b | - | - | - | - |
| c | 10* | 1 | 1 | 2 |
| d | 7 | 28 | 2 | 6 |
| e | - | 1 | - | - |

**GROUP:** First year university level

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 6 | 1 | - | 2 |
| b | - | 1 | - | - |
| c | 11* | 1 | 1 | - |
| d | 8 | 13 | - | - |
| e | 3 | 3 | - | - |

## RESPONSES TO QUESTION 6.3

**GROUP:** Standard 10

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 18* | 23 | 5 | 2 |
| b | - | - | 2 | - |
| c | 1 | 10 | 5 | - |
| d | 2 | 11 | 2 | 1 |
| e | 1 | 1 | - | - |

**GROUP:** First year university level

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 25* | 11 | 3 | - |
| b | - | - | 1 | - |
| c | 2 | 4 | - | - |
| d | - | 4 | - | 1 |
| e | - | - | - | - |

## RESPONSES TO QUESTION 7

**GROUP:** Standard 10

| REASON \ ANSWER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 4 | 2 | 2 | 2 |
| b | 7 | 2 | 4 | 2 |
| c | 22 | 1 | 4 | 13 |
| d | 6 | - | 4* | 3 |
| e | - | - | 1 | 3 |

**GROUP:** First year university level

| REASON \ ANSWER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 1 | - | 12 | 1 |
| b | 1 | - | 1 | - |
| c | 16 | - | 1 | 4 |
| d | 4 | - | 7* | 1 |
| e | 1 | - | 1 | - |

## RESPONSES TO QUESTION 8

**GROUP:** Standard 10

| REASON \ ANSWER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 2 | 12 | 17 | 5 |
| b | 3 | 10 | - | 2 |
| c | 2 | 4 | 2 | 12 |
| d | 5* | 2 | - | 6 |
| e | 1 | 1 | - | 1 |

**GROUP:** First year university level

| REASON \ ANSWER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | - | 4 | 7 | 1 |
| b | 2 | 1 | 1 | - |
| c | 1 | 4 | 2 | 12 |
| d | 12* | 1 | - | 3 |
| e | - | - | - | - |

## RESPONSES TO QUESTION 9.1

**GROUP:** Standard 10

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 1 | 4 | 7 | 5 |
| b | 1 | 3 | 8 | 3 |
| c | 1 | 11 | 10 | 2 |
| d | 1 | 1 | 20* | 6 |
| e | - | - | 3 | 1 |

**GROUP:** First year university level

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | - | 2 | - | - |
| b | - | - | - | - |
| c | - | 3 | 4 | 2 |
| d | - | - | 38* | 1 |
| e | - | - | - | 1 |

## RESPONSES TO QUESTION 9.2

**GROUP:** Standard 10

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 6 | 2 | 4 | 2 |
| b | 24* | - | 11 | - |
| c | - | 11 | 6 | 3 |
| d | 4 | - | 7 | 2 |
| e | 2 | - | 2 | - |

**GROUP:** First year university level

| REASON | ANSWER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 3 | - | - | - |
| b | 36* | - | 3 | - |
| c | 2 | - | 2 | - |
| d | 3 | - | - | 1 |
| e | 1 | - | - | - |

## RESPONSES TO QUESTION 9.3

**GROUP:** Standard 10

| REASON \ ANSWER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 11 | 3 | 2 | 16 |
| b | 2 | - | 1 | 5 |
| c | 2 | 2 | 6 | 5 |
| d | 2 | 2 | 2 | 26* |
| e | - | - | - | - |

**GROUP:** First year university level

| REASON \ ANSWER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 10 | 3 | 1 | 9 |
| b | 1 | 1 | - | 1 |
| c | - | 2 | - | - |
| d | 3 | - | - | 20* |
| e | 1 | - | - | - |