UNIVERSITY OF ALBERTA

STUDENTS' ALTERNATIVE CONCEPTIONS ABOUT GENETICS AND THE USE OF TEACHING STRATEGIES FOR CONCEPTUAL CHANGE

BY

WANCHAREE MUNGSING ©

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled STUDENTS' ALTERNATIVE CONCEPTIONS ABOUT GENETICS AND THE USE OF TEACHING STRATEGIES FOR CONCEPTUAL CHANGE submitted by WANCHAREE MUNGSING in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in SCIENCE EDUCATION.

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To my parents

who always inspired their children

to greater achievements.

ABSTRACT

The purpose of this study was to identify alternative conceptions held by grade 11 (Mathayom 5) Thai students in the area of heredity and to compare the effectiveness of two instructional approaches, identified as the current self-developed teaching approach and the cooperatively-designed teaching approach, in bringing about valid understanding of those alternative conceptions.

115 students enrolled in three upper secondary schools in Khon Kaen, Thailand were periodically administered the written tasks which were composed of concept mapping, general public notions related to heredity, and specific genetic concepts. Also, six selected students from each class were interviewed prior to and following instruction of the heredity unit in order to probe the reasons they gave during the written tasks. Classroom observations, lesson plan reviews, and teachers' dialogic interviews were performed to gather information about classroom implementations.

Thai students were found to possess alternative conceptions similar to ones reported in previous research studies and others that had not been identified.

An analysis of classroom implementation revealed that the teachers who used current self-developed teaching approaches were generally not sensitive to students' alternative conceptions. Whereas, the teacher who used a cooperatively-designed teaching approach was partially successful in implementing conceptual change strategies. Some difficulties in implementing the strategies were observed.

Series of one-way ANOVA's and multiple analysis of variance (MANOVA) were used to analyze the written task scores across five different sessions. It was found that students taught using the cooperatively-designed teaching approach performed better in concept mapping and had better understanding of the concepts related to heredity than students instructed via the teacher's self-developed teaching approach.

It was concluded that the cooperatively-designed teaching approach aimed at correcting students' alternative conceptions was more effective than the current teachers' guide-based approach. The students in a treatment group had fewer alternative conceptions after instruction than the students in other groups. The study

suggested a need for curriculum development and application for teacher education and training regarding the constructivist view of learning.

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The problem

Introduction

During the past two decades, there has been an increasing interest in the study of alternative conceptions in science held by students. The majority of research works in this area have focused on investigating physical science phenomena; fewer studies have dealt with biological science phenomena (Haslam and Treagust, 1987). For example, research has been reported regarding students' understanding of specific concepts in the areas of electricity, energy, force, heat, and mechanics. Studies described in the literature include heat and temperature (Erickson, 1979), mechanics (Gilbert *et al.*, 1982b), changes of state of water (Osborne and Cosgrove, 1983), energy (Solomon, 1983), vector characteristics (Aguirre and Erickson, 1984), electricity (Shipstone, 1984), motion (Halloun and Hestenes, 1985), constituents of matter and the notions of acids and bases (Cros *et al.*, 1986), Newton's third law (Terry and Jones, 1986), and changes in the state of matter (Stavy, 1990). Furthermore, Rogan (1988) pointed out that very few studies have concentrated on a description of ways in which those alternative conceptions interact with instructional techniques and the incorporation of research findings into teaching materials and strategies. Recently, more studies dealing with conceptual change have been reported (Finley *et al.*, 1992).

Importance of the Study

The relevant concepts which students bring into the classroom are the most important factors influencing the learning of new concepts (Ausubel *et al.*, 1978). In other words, students' subsequent achievement depends on the preconceptions they held prior to formal instruction. Also, students can interpret different meaning from instruction and probably these meanings are not congruent with the intended one (Anderson and Smith, 1986). Most studies have occurred in North America, Britain, and Australia, but this field of research received very little attention from Thai researchers.

Because intuitive ideas about one concept lead to alternative conceptions about other concepts (Westbrook and Marek, 1992), the teacher must be aware of these alternative conceptions and needs to take steps to eliminate misinterpretations as well as to prevent future alternative conceptions. Then, in order to help students reshape and restructure their knowledge, the crucial questions to be asked are: What alternative conceptions do Thai students hold in common in particular areas?, How does one implement teaching strategies in classrooms?, and How can this new approach be designed to be relevant to the Thai context realities?

One area of biology in which students have learning difficulties is genetics (Johnstone and Mahmoud, 1980, and Longden, 1982). A survey of high school science teachers (Stewart, 1982 a) indicated that Mendelian genetics, meiosis and mitosis, and the chromosome theory of inheritance were considered among the most difficult as well as the most important topics of study for high school students. Genetics is a central part of the secondary and higher education biology curriculum. The thorough understanding of genetics is important to the understanding of biology as well as of the impact of scientific technology on society (Browning and Lehman, 1988) and results as well in helping to solve the dilemma of social rejection of genetic engineering. In Thailand, the units on heredity make up about 15% of the grade 11 and 12 biology courses.

In Thailand science education is seen as a tool for improvement of the quality of life. At the same time, it is also a training to produce qualified future scientists for the needs of national manpower. Unfortunately, the Thai literature about students' alternative conceptions and the use of teaching strategies that facilitate students' conceptual change is very limited. It is not enough for teachers to give consideration and take actions in a process of reconstructing students' knowledge. Thus, it will be useful to provide more information about the constructivist view of learning. The knowledge of students' alternative conceptions about heredity can help biology teachers become more sensitive to students' ideas and be able to base instruction on their understanding of their students' prior knowledge (Gilbert *et al.*, 1982a and Rogan, 1988). Also, if designed instructional strategies can promote appropriate conceptual shifts within students, perhaps teachers will be encouraged to learn what their students know about those concepts and develop their teaching strategies in response to that knowledge. The results of this study will further be a valuable reference for planning the instruction of future teachers as well as the in-service workshops for current teachers. Curriculum developers, including writers of textbooks and teachers' guides, can also utilize the information in identifying trouble areas in genetics instruction about which the teacher must be sensitive as well as developing teaching materials and teaching strategies.

Purpose of the Study

This research proposes to:

1. Identify some alternative conceptions held by grade 11 Thai students in high school biology relating to the concepts associated with the study of heredity,

2. Design lessons to help students develop appropriate scientific conceptions, and,

3. Determine whether cooperatively designed lessons can promote the development of more accurate conceptual understanding.

Research Questions

The research questions focus on the learning of concepts in the field of genetics by Thai students, and are:

1. What are the common alternative conceptions that grade 11 Thai students hold about heredity prior to and following two instructional treatments? (One treatment is the cooperatively designed instruction aimed at correcting students' alternative conceptions and the other treatment is the current teacher-designed instruction.)

1.1 What are the preconceptions that the students hold before instruction?

1.2 What are the alternative conceptions which arise during instruction?

2. How can knowledge of students' alternative conceptions influence the way in which the teacher plans and presents the lessons?

3. How effective are designed lessons which are aimed at correcting students' alternative conceptions?

3.1 Which kinds of alternative conceptions can be changed in a scientifically correct direction through the use of "teacher-designed" instruction plans?

3.2 Which kinds of alternative conceptions can be changed in a scientificallycorrect direction through the use of "cooperatively-designed" instruction plans?

3.3 Which kinds of alternative conceptions persist in spite of instruction?

The research compares learning through two instructional treatments. The data will include: (a) students' responses to written tasks, (b) students' comments during interviews, (c) the lesson plans for instruction, (d) classroom observations, and (e) teacher informal interviews.

Five different sessions of written tasks were given to students periodically before, during, immediately after instruction, and four months after instruction to determine the alternative conceptions and conceptual change. Two interviews were conducted with selected students to probe into the reasons for the responses they gave on the written tasks. These interviews occurred after administration of the first and the fourth session tasks. Classroom observations were performed during the instruction of the heredity unit to provide more details of activities in the classroom supplemented by the lesson plans, and informal teacher interviews.

Definition of Terms

For the purpose of this study, the basic terms are defined as follows:

Alternative conceptions. Alternative conceptions are conceptions that do not conform to current scientific conceptions. These conceptions are held strongly and persistently by the students. Alternative conceptions which develop before instruction takes place are referred to as preconceptions after Abimbola, 1988.

Clinical interview. A clinical interview is based on the interview process used by Swiss psychologist Jean Piaget. Its chief goal is to ascertain the nature and extent of an individual's knowledge about a particular area by identifying the relevant conceptions he or she holds and how he/she perceives relationships among those conceptions (Posner and Gertzog, 1982).

Concept mapping. Concept mapping is a pedagogical technique to help students see explicitly how new concepts can be related to previously learned concepts (Novak, 1981a). The simplest concept map would be two concepts linked by logical connectives. A more complex concept map may begin to illustrate new meanings to students and hence to extend their conceptualizations.

Conceptual change. Conceptual change is a complex process in which students give up one set of conceptual understandings by adopting another irreconcilable set. There are two phases of conceptual change in learning (Posner *et al.*, 1982). The first phase is called assimilation, where existing concepts are adapted to deal with new phenomena. The more radical form of conceptual change is called accommodation. This happens when a student's current concepts are inadequate to allow the acceptance of some new phenomenon. Therefore the student must replace or reorganize the original concepts.

Cooperatively-designed instructional unit. A cooperatively-designed instructional unit is one which the researcher and a teacher prepare teaching plans together, which they believe will deal with students' alternative conceptions.

Genetics. Genetics is a branch of biology that deals with heredity and variation of organisms. The study includes how qualities and characteristics are passed on from one generation to another by means of genes.

Learning difficulties. Learning difficulties occur when students have not reached a particular stage of intellectual development, thus certain concepts are beyond their intellectual ability (Oldham, 1982).

Science knowledge. The term "science knowledge" generally has two meanings (Abimbola, 1988). It may refer to the expert's knowledge of science where sources of the knowledge are professional science journals and standard textbooks. Another meaning refers to the knowledge obtained from formal instruction in science. The teacher is expected to present science knowledge to the students in a manner which reflects the expert's knowledge.

Tasks. Tasks are any academic activities associated with instruction that are engaged in by students, usually at the teacher's behest, for the purpose of acquiring and/or using knowledge skills, or strategies (Anderson, 1989).

Teacher-designed instruction. Teacher-designed instruction is instruction in which the teacher practices her/his own style of teaching, usually based upon the teachers' guide developed by the Institute for the Promotion of Teaching Science Technology and the teacher's previous experiences.

Delimitation

The study involved grade eleven students who were taking biology within three urban secondary schools. All the students in 3 classes were asked to participate in this study and were taught by their usual biology teachers. Two classes were taught the topic of heredity by teachers who planned their own lessons. The purpose of using different teachers in each controlled class was to reduce the variation in teachers' ability to implement instruction. Another class was taught by a teacher who used cooperatively-designed lessons to deal with the students' alternative conceptions about heredity.

The other variables which may contribute to students' outcomes of learning, such as environmental variables (both in and out of the science classroom) and students' attitudes and learning styles, were not considered within the study.

Assumptions

1. It is possible to determine students' alternative conceptions by their responses to the written tasks and during interviews.

2. Students' conceptual changes can be determined by comparing responses to the tasks prior to and following instruction.

3. Students' conceptual changes result from instructional treatment as opposed to maturation or out of school experience.

Limitations

1. This study was limited to 3 classes and generalization to any other population may be limited to the extent that the population is similar.

2. Interpretation and explanation of the significance of the events were limited by the extent to which the classes were observed. However, the fieldnotes were given to the teachers and they were invited to make any additions, deletions, or alterations to the fieldnotes. These helped in the validation of the observations.

3. In the design of this study, three interviews were planned for each student. However only two were conducted because of the short duration in which the unit was taught. Consequently, interviews aimed to probe some preconceptions and changes of ideas during instruction were impossible.

4. The inheritance unit was taught at the end of the school year when there were many statutory holidays and another local festival. The teachers who participated in this study were pressured to cover the syllabus. The unit instruction, especially the teacher-designed teaching approach classes, then, was performed in a shorter duration than what was advised in the teachers' guide. This factor may have affected the differences in the outcomes.

Research Variables

The independent variables of the study were the instructional treatment and the teachers' awareness of students' alternative conceptions. The design of this study took the following form:

Class A: a teacher who was aware of students' alternative conceptions used the cooperatively-designed lessons planned by her and the researcher and aimed at changing the students' alternative conceptions. The teaching and learning activities focused on conceptual change strategies.

Class B and Class C: teachers who may have knowledge of their students' alternative conceptions developed their own lesson plans and designed their own preferred teaching/learning activities.

Each of the three teachers was informed about the purpose of the study. He/she was also given the marks of his/her students' responses to the tasks for each session, but discussion about the results in relation to planning instruction occurred only with teacher A.

The dependent variables were the scores obtained from written tasks and concept mapping before, during, and after instruction, and the descriptive analysis of students' conceptual change as determined through written tasks, concept mapping, interviews, student notes and classroom observation.

Chapter II

Review of Related Literature

Introduction

The review is presented into four sections. The first section discusses theoretical background which underlies the research concerning students' alternative conceptions. The second section focuses on defining concepts and alternative conceptions. The third section reviews related research studies and articles on alternative conceptions and the fourth section presents the background of Thai Education.

Theoretical Background

There are two main schools of psychology of learning: empiricist/positivist and constructivist. A significant difference between the two schools is the way in which they conceive what knowledge is and how knowledge has been achieved (Nussbaum, 1983). For the empiricists, knowledge is only what can be proven through observations and logic. Knowledge is inductively accumulated. Therefore, any conception that is different from that of the accepted scientific community is labeled "misconception." The sources of misconceptions are either faulty observations or misapplications of logic. Consequently, the way to correct students' misconceptions is to teach them to carry out more accurate observations followed by careful logical procedures. The empiricist/positivist view was popular until the beginning of the twentieth century (Nussbaum, 1989).

At the beginning of the twentieth century, a new school of psychology of learning began to replace the view of the logical empiricist. Instead of believing that knowledge is out there to be discovered, the constructivist view knowledge as a human construction. Man is not a "tabula rasa" for the reception of sense. Rather, knowledge, beliefs, theories, and expectations determine our perceptions. The sense made of any event is thus seen to depend not only on the situation itself but also on the individual's interpretation of its meaning.

The theoretical background for most of the research concerning students' alternative conceptions in science has been guided by constructivist perspectives. This tradition views that a learner's existing ideas are important in responding to and making sense of stimuli. The learner makes sense of experience by actively constructing meaning (Magoon, 1977). Learning may involve changing a person's conceptions in addition to adding new knowledge to what is already there. Hence in science classrooms, when students' preconceptions are different from scientific ideas, instruction does not just instill knowledge but teachers must also try to change existing conceptions.

Constructivist view is quite congruent with Ausubel's psychology of learning (Novak, 1985). Much of the research in science education that explores students' conceptions is influenced by his theory of meaningful learning (Preece, 1984). Ausubel defines meaningful learning as "non-arbitrary, non-verbatim, substantive incorporation of new knowledge into a person's cognitive structure" (Novak, 1985, p. 190). The theory focuses upon three concerns: (a) how knowledge is organized, (b) how a learner's mind works to process new information, and (c) how teachers can apply these ideas when they present new material to students.

Later in 1968, Ausubel presented the theory of cognitive learning which indicated that the most important factors influencing the learning of new content are concepts that already exist in a student's cognitive structure (Ausubel *et al.*, 1978). The theory suggests that effective teaching must identify those existing concepts and then build upon them.

The idea that learners' existing ideas may have impact on their interpretation of classroom instruction has led to the development of a theory, a philosophy, and a model of learning as conceptual change. Contemporary philosophy of science views knowledge acquisition as arising from the interaction between experience and our current conceptions. Conceptions are preconditions of experience, which means that we cannot see what we cannot conceive. Therefore, currently accepted ideas in the scientific community do not guarantee their truth. The ideas are accepted because "they had some success in accounting for some range of experience, that they have survived over their competition and that they are products of some degree of testing and refinement" (Strike and Posner, 1985, p. 215).

The conceptual change theory believes that students' ability to learn and what they learn, depend on the conceptions which they bring to the experience. The process of learning involves the transformation of conceptions. New ideas are not merely added to old ones, they must interact with existing ideas, and sometimes, the alteration of both is required.

Conceptual change may be akin to Kuhnian paradigm shifts where a major conceptual revision is required or to Lakatosian shifts when conceptions change gradually.

A model of learning as conceptual change has been proposed by Hewson (1981) and Posner *et al.* (1982). The model identifies conditions which need to be satisfied before a person will change conceptions. Those conditions are that the new knowledge needs to be (a) ***intelligible*** (meaningful), (b) ***plausible*** (truthful), and (c) *fruitful* (useful). However, if a new conception conflicts with existing conceptions, the conceptual change will occur only when the learner becomes dissatisfied with the existing conceptions. He or she must encounter difficulties in attempting to solve the problems or make sense of something with current concepts. Those collected unsolved puzzles or anomalies make the individual view an existing concept with some dissatisfaction and lead them to consider a new plausible one.

The underlying theoretical basis for this study is the constructivist view of learning, Ausubel's theory of meaningful learning and conceptual change theory.

Concepts and Alternative Conceptions

Concepts are "packages" of meaning; they capture similarities and differences, patterns, or relationships among objects, events, and other concepts (Pines, 1985). Concepts are grouped into "conceptual frameworks" which are used to predict and explain facts and events. Concepts, therefore, have the most potential for the development of cognitive skills and logical thought process. They are used for interpreting, inferring, generalizing, as well as, to build other more powerful concepts and principles (Hurd, 1970). Concepts can be categorized into two levels, concrete and abstract. Concrete concepts are constructed by referential relationships to physical objects and experienced events, while abstract concepts are invented by relating subordinate concepts to one another (Pines, 1985). Abstract concepts are more sophisticated than concrete concepts.

The intellectual environment in which a person lives: cultural beliefs, accepted theories, observed facts and events, and language, has impact on the development of concepts. This intellectual environment may promote the development of some concepts as well as inhibiting the development of others (Hewson, 1985).

Hurd (1970) defines concept as:

> ....a synthesis or logical relationship given to relevant information by the student; it is a product of his/her own imagination, insight, or reasoned judgment. A concept is also more than a collection of organized facts. Facts are essentially bits of information, concepts are mental constructs resulting from the class identity given to the facts by the learner (p. 57).

Fieldman (1987) shares his idea about a concept as the following:

> A concept is a categorization of objects, events or people that share common properties. Through the use of concepts, we are able to distill the complexities of the world into more simplified and therefore more easily usable-cognitive categories. Concepts allow us to classify newly encountered objects into a form that is understandable in terms of our past experience (p. 210).

A conception is a way of seeing something, a qualitative relationship between an individual and some phenomena (Johansson *et al.*, 1985). The term conception is used to indicate a functional unit of thought which consists of both propositional (knowing that) and procedural (knowing how to) aspects. A conception can be visible only through an individual's reflection.

Students bring into instruction a conception that they have developed through interpretation of personal experience. These conceptions often differ from the existing consensus view of scientists (Driver, 1981, and Osborne, 1982). Various researchers apply different terms to the conception which is incompatible with scientific theory; for example, alternative frameworks (Driver and Easley, 1978), intuitive ideas (Hawkins, 1978), naive belief (McCloskey *et al.*, 1980), preconceptions (Clement, 1982), alternative conceptions (Gilbert and Watts, 1983, and Hewson, 1985), or misconceptions (Fisher, 1983, and Wandersee, 1986). Whatever they are called, these terms refer to students' ideas which are different from the "proper" scientific viewpoint.

Halloun and Hestenes (1985) state that " ... a misconception is knowledge derived from personal experience which is incompatible with established scientific theory" (p. 1058). Similarly, Cho *et al.* (1985) identified the term misconception as "any conceptual idea whose meaning deviates from the one commonly accepted by scientific consensus" (p.707). As well, Wandersee (1986) defines that " ... misconception is often used to describe an unaccepted (though not necessarily 'incorrect') interpretation of a concept by the learner" (p. 581). According to Abimbola (1988), the term "misconception" is inappropriately based on its relationship to empiricism/positivism. This study adopted the term "alternative conception" as used by Gilbert and Watt, 1983, and Hewson, 1985.

Congruent with the constructivist view of learning, alternative conceptions occur because the student is an active participant in construction of his or her own knowledge. Different people use their existing knowledge to make sense of the world; therefore it is possible that they may construct different alternative conceptions even when presented with the same information (Hewson, 1985). Alternative conceptions may stem from early childhood, emerge in the course of formal instruction, and may be acquired informally in later life (Mintzes, 1989). Alternative conceptions which arise before instruction takes place are called preconceptions.

The majority of research has focused on investigating students' understanding and identification of alternative conceptions. For example, Wandersee (1986) found that when asked about photosynthesis concepts, many students believed that "soil is food." This view stubbornly persisted across grade levels from elementary school through colleges. Other studies of Cohen *et al.* (1983) and Novick and Nussbaum (1981) illustrated that a large number of college students and other groups of adults, even after many years of schooling, gave responses similar to elementary school children when interviewed on fundamental concepts of science. It is clear that our current approaches to the teaching of science fail to bring about a significant change in students' understanding.

Teaching a new science concept is a difficult job, but correcting an alternative conception is much more difficult. For the person who holds it, an alternative conception feels like the truth (Eaton *et al.*, 1983).

Related Alternative Conception Research

There are a number of studies which focus on alternative conceptions in science held by students. The studies are reviewed under the following categories: methods of investigation, sources of alternative conceptions, alternative conception studies in genetics and studies dealing with alternative conceptions.

Methods of investigation

Most researchers use in-depth interviews with children to determine their alternative conceptions. Longford (1983), Ault *et al.* (1984), Aguirre and Erickson (1984), Finley (1985), Lawson (1988), and Piburn *et al.* (1988) conducted clinical interviews to diagnose students' alternative conceptions. This approach was pioneered by Piaget in the 1920's (Posner and Gertzog, 1982) for investigating the nature and extent of children's knowledge. The goal of clinical interviewing is to ascertain the nature and extent of an individual's knowledge about a particular domain by identifying the relevant conceptions he or she holds and the perceived relationship among those conceptions. The researchers who used this approach believed that clinical interviews are particularly rich sources of information about an individual student's ideas.

Other methods of interviewing, called the "Interview–about–Instances" approach and the "Interview–about–Events" approach were conducted in many studies. The Interview–about–Instances approach explores children's meanings for words by means of taped individual interviews. Children were asked to decide whether the situations were examples or not of their conception of the word and give a reason why. This method has been used to explore children's meanings from many words: for example; "force" (Osborne and Gilbert, 1980), "living" (Stead, 1980), "light" (Stead and Osborne, 1980), "animal" (Bell, 1981), "electric current" (Osborne, 1981) and "gravity" (Stead and Osborne, 1981).

The Interview–about–Events approach places more emphasis on eliciting children's view of the world within the overall framework of children's alternative conceptions. It involves an individual discussion with an interviewee about an articulated series of demonstrations. The method has been used to explore children's views on "physical change" (Cosgrove and Osborne, 1981), "chemical change" (Schollum, 1981), and the "particle nature of matter" (Happs, 1981). A sequence of steps used to investigate children's views on physical change is also provided in Gilbert *et al.* (1982a).

A number of studies have been conducted by using the methods of student responses to specific tasks. Students were individually interviewed on a number of tasks designed to probe understanding of some aspects of science. The method has been used to investigate students' understanding of inheritance by Engel Clough and Wood-Robinson (1985), and Engel Clough *et al.* (1987). Also Hesse (1988) investigated conceptions of chemical change using specific tasks.

Another popular method used in this area of studies is concept mapping. Mapping is "a human exercise in knowledge construction or meaning making" (Wandersee, 1990, p. 924). The technique of concept mapping can help elicit knowledge of the relevant concepts that already existed in the learner's cognitive structure. Those researchers who have used this method are Novak *et al.* (1983), Martin (1983), Feldsine (1988), and Nocente (1988).

Written tasks, questionnaires, free response questions, and multiple-choice tests also play an important role in the studies of students' alternative conceptions. Researchers using such methods include Wheeler and Kass (1978), Wandersee (1986), Haslam and Treagust (1987), Dupin and Johsua (1987), Ridgeway (1988), Schmidt (1988), and O-saki and Samiroden (1990).

Therefore, it could be concluded that students' alternative conceptions can be determined by interviews and tests of various types, concept mapping, written tasks, and questionnaires.

Sources of alternative conceptions

Lawson (1988) conducted clinical interviews with three siblings: a preschooler, a third grader, and a fifth grader to find out how a person acquired knowledge in childhood. Lawson chose children from the same family for the purpose of controlling large scale environment influences, and the varied ages could provide the comparison of trends in knowledge development. The results suggested that knowledge acquisition follows the gradual accretion pattern. The primary source of knowledge is adult authority; for example, books and television, rather than personal knowledge. The researcher concluded that only a few students bring with them highly formulated alternative conceptions about biological science.

On the belief that textbooks are the major sources of information as well as alternative conceptions, Cho *et al.* (1985) investigated alternative conceptions found in the three popular high school biology textbooks: *Biological Science: An Ecological Approach* (BSCS, 1978); *Biological Sciences: An Inquiry into Life* (BSCS, 1980); and, *Modern Biology* (Otto, Towle, & Bradley, 1981). They found that each textbook provided four sources of alternative conceptions and difficulties: conceptual organization, conceptual relationships, use of terms, and mathematical elements. All three textbooks introduced meiosis and genetics separately in different chapters and none of the three textbooks attempted to interrelate some significant basic concepts. In addition, the textbooks misused some terms such as gene, allele, and mutation. All three textbooks introduced the Punnett square to solve problems without demonstrating the random segregation of chromosomes and independent assortment of genes.

Alternative conception studies in genetics

Research studies conducted in relation to the understanding of genetics are extensive and varied. Kargbo *et al.* (1980) developed a clinical interview method to identify children's beliefs about inherited characteristics. The interviews with 32 Canadian children, ages 7 to 13, indicated that there was a wide range of beliefs among children of all age levels regarding acquired inherited characteristics. Many children, regardless of age, believed that phenotypic changes can be transmitted to the offspring. They seldom used probabilistic thinking in making predictions about offspring. The researchers concluded that children's responses could be classified into four categories of explanations: environmental, somatic, naturalistic, and genetic principle.

Similar findings were found in the work of Engel Clough and Wood-Robinson (1985). They interviewed 84 students, aged 12-16 years, to probe into students' beliefs about inheritance. The study indicated that students had already developed their ideas before the topic was taught in school. The results further revealed that students held viewpoints which were different from scientific ideas. Many students believed in environmentally produced inheritance and generally appeared not to understand the equality of parental gene contribution or mechanisms of inheritance. The study also found that there was some improvement in understanding in the older age groups but many alternative conceptions persisted regardless of age.

Hackling and Treagust (1984) explored high school students' understanding after instruction. The study aimed at investigating the concepts and propositions which were necessary for understanding the mechanisms of inheritance and determining which concepts and propositions were not understood or misunderstood. The partially standardized interview results revealed that the concepts and propositions about chromosomes, genes, meiosis, and fertilization were necessary for an understanding of the mechanisms of inheritance. They also found that many students held various alternative conceptions. Some believed that gametes carry pairs of chromosomes and pairs of genes from the pairs found in the parents' body cells. Many failed to understand probability in inheritance and had difficulties in explaining the meaning of the terms "dominant," "recessive," and "blending inheritance." The study further indicated that students failed to recognize the relationship between mitosis and growth or development.

Similarly, Longden (1982) examined the problems faced by 10 British high school students while learning genetics. By using in-depth recorded interviews based on genetically oriented tasks, he found that students had difficulties with the relationship between genes and alleles, chromatids and chromosomes, and the replication of DNA and meiosis. Students also had trouble with the symbolic replication and mathematical elements of the topic. Longden concluded that some students' alternative conceptions were related to (a) the nature of concepts present in genetics, such as the frequent representation of meiosis by a fixed inanimate stage diagram and the distinction between "gene," "allele," "chromatid," and "chromosome;" (b) pedagogical presentation such as the separation in teaching time between the presentation of meiosis and the introduction of genetics; and (c) the type and extent of practical support experience available to the student.

The study with American high school students was reported by Stewart (1982a). He conducted a case-study research to assess students' knowledge and problem solving strategies in solving genetic problems. He found that the students fail to understand the relationship between symbols of the Punnett square they used and segregation of chromosomes/genes. Also, they did not associate the algebraic methods to meiosis process. Lastly, the students demonstrated difficulty to describe how pairs of the following concepts were related: gene-allele, allele-chromosome, gamete-chromosome, zygote-allele, allele-trait, and gene-trait.

Another report dealing with problem-solving in genetics was presented by Tolman (1982). Using a "think-out-loud" technique, he found that the students had difficulties in understanding the relationship between alleles and chromosomes, as well as, the segregation and assortment of chromosomes during the meiosis process. He suggested that meiosis should be integrated into the lesson unit and that the teaching sequence should be revised.

The following year, Stewart (1983) reported a study which focused on the procedural and conceptual knowledge shown by 27 students as they each solved a monohybrid and a dihybrid problem. Using interviews which were a combination of thinking out loud procedures and a clinical interview format, Stewart found that three students could not even begin the monohybrid problem because they could not construct proper allelic symbols. Another seven students successfully completed the monohybrid problem but had difficulty with the dihybrid task. These seven students had difficulties constructing allelic symbols and determining the genetic composition of the parental gametes. Although 17 students were successful in producing correct solutions to both problems, Stewart warned that most students were not meaningfully solving the problems because they were unable to connect meiosis to the problem solutions.

To assist students to learn genetics in a more meaningful and easier way, Thomson and Stewart (1985) analyzed the conceptual and procedural knowledge which is necessary for genetics problem solving and produced an algorithm in which the inheritance patterns have to be determined prior to attempting solutions. The results of interviews administered with about 200 students indicated that some students had difficulty in constructing correct symbolic keys for alleles. Consequently, they could not generate correct gamete types. The researchers concluded that genetics instruction should help students to have a meaningful understanding of basic genetics by relating problem-solving algorithms to conceptual knowledge. Example of problems and questions which have proved successful in assisting students in that meaningful way were given.

A similar study was reported by Browning and Lehman (1988). They investigated 132 elementary education students' alternative conceptions in genetics problem solving through a review program on microcomputer. The program required the students to solve two monohybrid and two dihybrid problems. Student responses were recorded on diskette and later analyzed for types and frequencies of alternative conceptions and difficulties in the problem solving process. The results indicated that the students had weakness in computation skills, difficulties in the determination of gametes, and difficulties in applying previous learning to new problem situations.

Stewart and Dale (1989) interviewed fifty high school students while they were solving monohybrid and dihybrid problems. They aimed at finding out how novices structured their conceptual knowledge of genetics and meiosis and how it influences their problem solving performance. The results indicated that most students were able to solve the problems but demonstrated alternative understanding of chromosome and gene movement during meiosis. The students also lacked conceptual knowledge which is necessary to operate the combination correctly. The researchers suggested that in order to help students develop an accurate understanding of meiosis, teachers should be aware of alternative views which occurred during instruction, evaluate students' success not only with regard to the correct answers but also in the processes they used in obtaining the solutions and in their ability to justify answers.

Another study that supports those previous reports was reported by Brown (1990). The researcher examined students' responses to a practical task which was given as part of an advanced level examination. The study indicated that a sample of 614 students held alternative conceptions about the process of meiosis and its relationship to Mendelian genetics. Three areas in which students demonstrated a lack of the appropriate concepts were: duplication of chromosomes into chromatids, sister chromatids carry the same alleles, and the concepts of heterozygous, allele, and locus.

Instead of just identifying alternative conceptions, Lawson and Thompson (1988) conducted a study to test the hypothesis that formal reasoning ability is necessary to develop scientific concepts in seventh grade students. The students were pre-tested to determine their reasoning ability, mental capacity, verbal intelligence, and cognitive style. Then, the students were given an essay test on principles of genetics and natural selection following instruction. The number of alternative conceptions was compared to the results from the pretest. There was a significant relationship only between the number of alternative conceptions and reasoning ability. Formal-operational students held significantly fewer alternative conceptions than did concrete-operational students.

The following year, Gipson *et al.* (1989) focused their interest on the relationships between formal-operational thought and conceptual difficulties in genetic problem solving. Two months after students were taught the Mendelian genetics unit, they completed a content-validated problem solving retention test and Piagetian interview tasks to measure intellectual development. The results indicated that there were no direct relationships among the three kinds of reasoning, proportional, combinatorial, and probabilistic. Formal-operational students had more success than transitional students, and transitional students had more success than concrete-operational students in the retention test.

The results from these research studies indicate that many students held several alternative conceptions in scientific knowledge. Sources of alternative conceptions are (a) science textbooks, (b) teacher's instructions, and (c) experiences commonly shared by many individuals. Alternative conceptions are consistent across different age and culture groups, and are resistant to change in response to traditional instruction.

Studies dealing with conceptual change

Recently, more interest has been placed on conceptual change (Finley *et al.*, 1992). The studies dealt with understanding how conceptual change occurs and teaching strategies which can alter students' existing alternative conceptions. Some research has viewed teaching for conceptual change in the way that teaching should be developed from children's beliefs. Gilbert *et al.* (1982a) recommended that the aim of science teaching could be viewed as the development of children's science. Children should be made aware that there is another scientist viewpoint, which is useful. And teachers should listen to, be interested in, understand and value the views that children bring with them to science classes, in order to be able to decide what to do and how to do it. The work of Rogan (1988) supports Gilbert and his colleagues' view. Rogan concluded that instead of ignoring alternative conceptions, teachers should design instructional sequences that lead students from some aspects of their existing knowledge to a specifically acceptable understanding of the concept.

A research study focusing on instruction designed to change students' conceptions was reported by Nussbaum and Novick (1981). They developed an instructional strategy designed to change students' conception of the nature of gases. The sequence of activities in those lessons was defined. However, the results indicated that about two-thirds of the students receiving the instruction still held with several alternative conceptions.

Similar results were reported by Smith and Lott (1983). They studied changes that occurred in the conception of a class of fifth-grade students as they experienced instruction designed to change their conception of how green plants get their food. All the students except one still retained their preconception or some hybrid conception. Consequently, they discussed some ways in which the teaching for conceptual change can go wrong.

Among those were: (a) students were often uncertain about empirical generalizations important to the strategy, (b) communication was sometimes hampered by systematic sources of ambiguities, (c) the instruction was in some ways attacking the wrong preconception, and (d) some important issues were not adequately framed through use of appropriate questions.

In contrast to the results of Nussbaum and Novick (1981), and Smith and Lott (1983), Zietsman and Hewson (1986) reported a successful study. They investigated the effects of instruction using microcomputer simulations and conceptual change strategies. The microcomputer program was designed in accord with a model of conceptual change to diagnose and remediate alternative conceptions of velocity. Results showed that, first, the microcomputer simulations were credible representations of reality, and second, that the remedial part of the program produced significant conceptual change in students holding alternative conceptions.

Also, Hewson and Hewson (1988) exemplified the two studies of instruction based on conceptual change ideas: the first of which addressed the concepts of mass, volume, and density; and the second, the concept of speed. They pointed out that teachers need to: (a) be able to diagnose their students' thoughts on the topic being studied, (b) make students clarify their own thoughts by well-planned, guided, questioning, and (c) provide students with factors necessary for conceptual change.

Another study was done by Targan (1989) to test the conceptual change model recommended by Posner *et al.* (1982) during instruction about the phases of the moon. The students were tested on their knowledge before, during, and after instruction. Targan found that the approach was effective in bringing about conceptual change. Students who held alternative conceptions before and during instruction could replace more scientific ideas. Also, those students who started the instruction without alternative conceptions gained more acquiring additional appropriate concepts.

Focusing on teachers' abilities to implement conceptual change strategies, Neale *et al.* (1990), evaluated the success of the institute training program. Ten teachers from grades K-3 were trained in a 4-week summer institute on the unit of light and shadows, then these teachers were assessed on their implementation of the strategies in their own classrooms during the following year. The assessment was done by an analysis of videotaped lessons, from interviews with students to measure their conceptions, teacher interviews and reports of their self evaluation. The results indicated that those teachers were successful in bringing about conceptual change in students. They were able in implementing conceptual change teaching. However, different teachers presented different levels of implementation.

In the area of genetics and related topics, there have been significant studies which focused on dealing with students' conceptions of inheritance, molecular genetics, and evolution. Allen and Mall (1986) believed that more carefully designed instructional method should result in better problem-solving procedures and assist students to overcome those difficulties. Rather than using a Punnett square algorithm, they directed students to solve genetics problems by carefully working through the processes of meiosis and fertilization in detail.

Scharmann (1990) tried to resolve students' alternative conceptions through small group discussion. The subjects were two classes of college freshman biology students. The students were pre- and post-tested for evolutionary biology concepts, attitude toward evolution, and understanding of the nature of science. Both classes received identical instruction except that the experimental group had an opportunity to discuss their position regarding the theory of evolution. They were encouraged to resolve conflicts arising from the discussion and then present the consensus position. Analysis of post-test data indicated that there were no significant differences for evolutionary concepts between the groups. However, the experimental group had a more positive attitude toward the study of evolution and a better understanding of the nature of science.

Bishop and Anderson (1990) investigated the effect of instruction on students' conceptions of natural selection and its role in evolution. The subjects were students with nonscience majors in a college biology course. Analysis of student responses to the pretests and post tests revealed that the students with an average of 1.9 years of previous biology courses had little understanding of the evolutionary process and there was no relationship between the amount of previous biology courses taken and either pretest or post test performance. Belief in the theory of evolution as historical fact was also unrelated to the test performance. Course instruction which was specially designed on the basis of an analysis of students' conception was moderately successful in improving students' understanding. Students' alternative conceptions found in this study were: (a) a need-driven adaptive process caused traits to change, (b) evolution was seen as a process that molds or shapes the species as a whole rather than individual members of a population possess a reproductive advantage, and (c) changes were seen as gradual changes in the traits themselves rather than to the proportion of individuals in population having the trait.

In the same year, Dreyfus *et al.* (1990) investigated some difficulties in the implementation of a conceptual change instructional approach. The sample of tenth grade students was stratified into three groups: high, medium, and low achievers. The students were interviewed in small groups to determine their alternative conceptions on perspiration, cell membrane, and the transmission of hereditary traits. During the interview, there was an attempt to determine and resolve conflicts with students. The findings could be categorized into three patterns of response:

(a) when conceptual conflict could be established on students' experience-bound concepts, the students could resolve the conflicts although some students went on to form new alternative conceptions based on their perception of the concept; (b) when conceptual conflicts could be established on pure "school knowledge," the students had difficulties to resolve the conflicts; and (c) when conceptual conflicts which had been initiated from other learned formal knowledge could be established, the students often failed to reject their preconceptions related to highly formal knowledge which was known to students as everyday implications. The results further indicated that the "more able" students enjoyed the conflicts and challenges, but the "less able" students tried to avoid these situations. The researchers concluded that the students' attitudes toward school knowledge were important.

On the other hand, Okebukola (1990) used a concept map to improve students' conceptions of genetics and ecology. The Lagos State University in Nigeria pre-degree students were randomly assigned to the experimental group and control group. The experimental group was instructed on how to prepare concept maps and was required to submit concept maps for each lesson. The students were pre- and post-tested using multiple choice item tests. The results indicated that the experimental group performed better. Therefore, the investigator concluded that concept mapping helped students to learn meaningfully because they were required to interrelate the multiple concepts that were involved in the topic.

This review of literature summarizes some researchers' attempts to determine effective strategies in enhancing student scientific concept formation. The strategies include curriculum and material design, instructional design, and teaching techniques.

Thai Education

The earliest form of education in Thailand may be said to have begun in the 13th Century. Early educational institutions were the monastery and the palace, and education was limited to mainly the aristocracy and the clergy. The Buddhist monasteries were opened to the public but only a very small portion of the population, mostly male, was trained in literacy skills and a particular profession. The palace, on the other hand, was restricted to the children of the royal families and to those of government officials (Ministry of Education, 1964).

Because the transmission of knowledge and skills were undertaken by the Buddhist monks, the teacher's duties were determined following Buddhist principles. He was to give good advice to his student, provide him with all knowledge, and protect him from all danger. The characteristics and roles of the Buddhist monks in terms of responsibility, deeds, and moral obligations became the images of the teacher in the past. The monk received great respect from people and so did the teacher. These expectations for an ideal teacher in the Thai society as well as a teacher's "respectable" image still exist up till now.

During the reign of King Mongkut (1851-1865), Western educational ideas were introduced and a school for common people was first opened in 1884 by King Chulalongkorn. Then the Department of Education was established in 1887 and became a full-fledged Ministry in 1892. Thus the school system was expanded and extended gradually to rural areas. This new "popular education" emphasized literacy, good citizenship, and a better standard of living for the people.

After the adoption of the system of constitutional monarchy in 1932, a National Educational Scheme was formulated. The scheme was to ensure that every citizen was provided with the four major aspects of education: intellectual, moral, physical, and practical (National Identity Board & Information Department, 1988).

A new 6-3-3 educational system was introduced in 1978. The major elements of its structure are as follows:

1. Primary education. During the six years of primary education, children will be taught basic language and literacy skills, simple arithmetic, social and health education, and creative activities. English is introduced as an optional subject during the fifth year of primary education.

2. Secondary education. Secondary education is divided into two three-year phases-the lower secondary level and the upper secondary level. It aims to provide the students with appropriate academic knowledge and working skills. More technical subjects and other foreign languages are introduced in addition to the continuing study of Thai, English, mathematics, science, and social studies.

About 65 percent of primary school children go on to receive secondary level education (Sinlarat and Kanari, Eds., 1987).

3. Higher education. This level of education aims at the full development of high level academic and professional manpower. Higher education provides two programs : the four year bachelor degree program and the one- to three-year diploma program. The former program is much more popular than the diploma program. Only about 20-30 % of the applicants can be admitted to the public universities. Therefore admission is done by a competitive national university entrance examination. A limited number of students goes to enroll in private institutions because these colleges are very expensive.

The language of instruction in Thailand at all levels is Thai, with the exception of some special major courses at some universities which are conducted in English.

Compulsory education begins at the age of seven and children are required to attend school until they have reached the age of fourteen.

Enrollment by levels of education is illustrated in Figure 1.

Educational administration is centralized and all schools throughout the country must use the same curriculum authorized by the Ministry of Education (Saphianchai and Chewprecha, 1984).

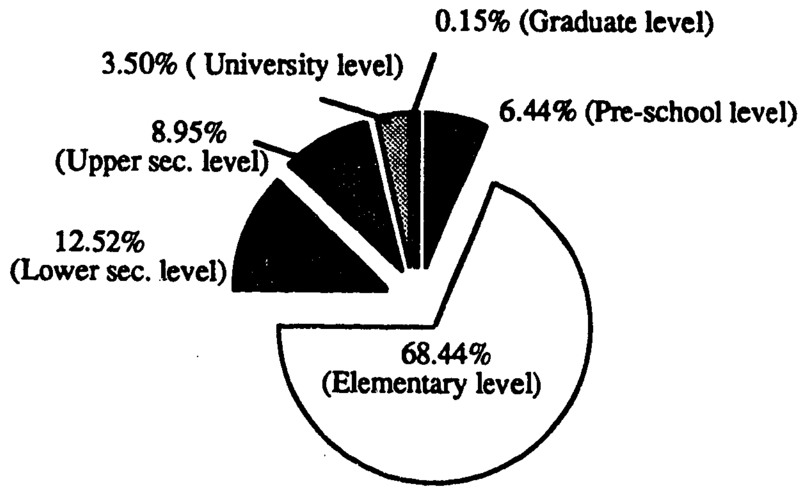


Figure 1. Enrollment by levels of education in 1985
(**Source**: The Institute of Population and Social Research, Mahidol University, 1987)

Science is a required subject at both secondary levels. The science course offered at the lower secondary level has the characteristics of an integrated science, but at the upper secondary level the non-science program students are required to take a specially designed subject called "Physical and Biological Science", whereas the science program students have to study two out of the three science areas: biology, chemistry, and physics. However, in practice, the schools usually require all students in each class to study the same subjects in any one year, with the exception of a few elective courses.

As indicated earlier, all schools throughout the country must use the same curriculum. The Institute for the Promotion of Teaching Science and Technology (IPST) was established in 1972 to develop new science and mathematics curricula for both primary and secondary school levels.

In addition to curricula, the IPST is also responsible for textbooks, teachers' guides, and equipment design. The curricula are adapted from the curricula which have been developed in the USA, Australia, and Britain. For biology, the IPST adapted materials from BSCS but used examples and data collected in Thailand for some local topics. The curricula are designed to be activity-based and student inquiry-oriented. A student textbook accompanied by a teachers' guide are produced for each grade level for each semester. The textbook has small amounts of detail because the emphasis is on experiments and practice of scientific skills. This nature of the student textbooks forces students to rely heavily on the supervisory function of their teachers and teachers to rely on the teachers' guides. Therefore the teachers' guide is the comprehensive source in studying science. It gives details about what to teach, how to teach, and how to lead the discussion to predetermined conclusions. As a result, many teachers intensively follow the instruction prescribed in the teachers' guide.

Usually, the instruction focuses on transferring the entire curriculum content. Students are somewhat passive participants in classroom activities. They attempt to absorb every necessary detail to achieve the standards required by the university in its entrance examination. The teachers, as well, try hard to prepare their students for accessing the highly professional oriented areas of further study. A competitive atmosphere dominates all classroom activities.

In conclusion, although the curricula suggest that a teacher should design his or her own lessons as appropriate for each situation, many teachers opt to adopt activities and materials described in the teachers' guide since all schools throughout the country must use the same curriculum authorized by the Ministry of Education and admission to the universities is done by a competitive national university entrance examination.

Chapter III

Research Procedures

Introduction

This chapter presents a detailed description of the research procedures included in the study. It is divided into 5 sections: (a) Overview of the design, (b) The sample, (c) Instrumentation, (d) Data gathering processes, and (e) Treatment of the data.

Overview of the design

The research aims at determining the Mathayom Five (Grade eleven) students' conceptions about genetics and comparing the effects of instructional approaches identified as conventional self-developed teaching approaches and a cooperatively-designed teaching approach aimed at correcting students' alternative conceptions. To achieve these aims, five different sessions of written tasks were given periodically, before, during, and after instruction to students of three participating classes in three different schools. The pre- and post-instruction interviews were conducted with six selected students from each class to probe into the reasons for the responses they gave on the written tasks. Classroom observations were performed during the instruction of the heredity unit to provide some information of classroom implementations. Lesson plans were reviewed and dialogic interviews were held with the teachers.

The sample

The sample for this study consisted of three teachers and 115 students in Mathayom Five (Grade eleven) biology classes of three upper secondary schools in Khon Kaen.

The students. The student participants in the study were from three different classes. Class A (35 students) were from Khon Kaen Demonstration School. This class was chosen because it was convenient for the researcher who was a faculty member to conduct any research works since this school was established for the purpose of being a laboratory for the Faculty of Education to experiment and research on curriculum, teaching, and learning. The other two classes were chosen from two public schools where students were similar to the first groups in the total academic abilities as determined by their average scores in examinations during the previous term and their own teachers. Class B consisted of 37 students from the famous academic school in town and Class C consisted of 43 students in the largest composite school.

The teachers. Three teachers involved in the study were teachers who completed at least a 4-year B.Ed with a major in biology teacher education and two years of teaching experience in biology. In order to reduce variations in teacher knowledge and competencies, two teachers were asked to participate in this study, using their usual teaching approaches. Another teacher was asked to use a cooperatively-designed teaching approach (conceptual change teaching approach) to a treatment group. The teacher from the demonstration school was contacted informally two months prior to the implementation of the heredity unit. When she agreed to participate in the study, two other teachers who had similar educational backgrounds to the first teacher were contacted.

In selecting these two teachers, the academic abilities of students in each school were also considered. The teachers were asked to suggest a class of their own where students' academic backgrounds were similar to those in the demonstration school.

Instrumentation

The instruments included: (a) written tasks given in five different sessions to determine students' alternative conceptions, (b) interviews with selected students to probe into their reasoning, and (c) classroom observations to provide information about instructional patterns in each class.

Formulation of student tasks. The written tasks designed to determine students' alternative conceptions were adapted from questions developed by Kargbo *et al.* (1980), Oram and Kaskel (1983), Engel Clough and Wood-Robinson (1985), Thomson and Stewart (1985), Allen and Moll (1986), and Stewart and Dale (1989). The questions can be classified into three groups: concept mapping, general public notions related to genetics, and specific genetic concepts as appropriate to Mathayom Five (eleventh grade) level. These tasks were given in five different sessions: (a) before any instruction of the heredity unit, (b) before the instruction of monohybrid cross, (c) before the instruction of dihybrid cross, (d) at the completion of the unit, and (e) four months after the unit was completed (See Appendix 1).

All written tasks were piloted with two Mathayom Six (grade 12) students and two Faculty of Education freshmen. Revisions to the tasks were made in response to the difficulties or confusion experienced by these participants.

Concept mapping. The first task given in each session was concept mapping. The students were given a list of concepts provided on a set of cards with one concept per card, so that they could move the words freely until they decided to draw an actual map. They then were asked to draw a concept map using those concepts. The concepts used in the list were drawn from those suggested by Stewart (1982a) who pointed out that students encountered difficulties in describing the relationship between those concepts. However, some of concepts have been removed or added as deemed appropriate for the objectives of the heredity unit to be taught. The list consisted of six concepts for the first session with three concepts added to the task for each of the two following sessions.

The questions. Following the concept mapping activities, the students were presented with a number of questions presented on paper. These questions were designed to probe students' understanding of some aspects of heredity and required the students to explain the reasons for their answer. They were required to respond in writing by explaining, identifying, or applying concepts related to the unit of heredity being studied. The questions, excluding concept mapping, can be classified into two groups: general public notions related to heredity, and specific genetic concepts. Some questions given on the post test were modified but still parallel to the original questions.

1. **Questions dealing with general public notions which related to heredity.** A number of questions were formulated to assess students understanding about the basic hereditary knowledge of their everyday world. These questions are as follows:

Questions # 2.1 and # 2.2 (pretest), drawn from Kargbo *et al.* (1980), probed students understanding of the difference between environmental and hereditary characteristics.

2.1 Suppose the tails of two dogs were cut short at a veterinary clinic when they were just two weeks old, if these two dogs later have a puppy, what will be the length of the tail of this puppy? Explain why.

2.2 What would happen if tails were repeatedly cut off over several generations-what kind of the puppies would you end up with? Why?

(Post test questions were modified as follows:) In an experiment of breeding mice, a scientist would like to see if he could get tailles mice. He cut off the tails of some adult mice and bred them. When these mice with the chopped-off tail are mated,

2.1 What kind of babies would these mice produce? Why?

2.2 Do you think that if he bred the mice with the chopped-off tail again and again he would get tailless mice? Explain your answer.

Question # 3.1 (pretest) drawn from Kargbo *et al.* (1980), determined students' viewpoints of probabilities of inheritance.

3.1 If a white male mouse and a black female mouse have six offspring, what colors would the offspring be? Why?

Question # 3.2 (pretest) also drawn from Kargbo *et al.* (1980), probed the understanding of the equality of genetic contribution by each parent during sexual reproduction.

3.2. Which one of the parent mice do you think will have a greater influence on the characteristics of the offspring? Why?

(Post test questions were modified after Allen and Moll, 1986 as follows:) A student placed a white female guinea pig in a cage with 3 male guinea pigs (one white and two black). Later the female gave birth to a white offspring.

3.1 Which of the males could be the father of the offspring? (if black color is dominant to white) Why?

3.2 Which one of the parent guinea pigs do you think to have a greater influence on the characteristics of the offspring? Why?

Questions # 4.1 and # 4.2, drawn form Engel Clough and Wood Robinson (1985), probed students' viewpoints about the likenesses and variations among the members of a family.

4.1 Can you explain why it is that children in the same family frequently look like one another?

4.2 Why are children in the same family not identical?

Questions # 6.1 and # 6.2 were drawn from Engel Clough and Wood-Robinson (1985). These questions asked about the possibilities of phenotypic change on the inheritance of human athletic skill.

A couple had trained hard to become good runners (though they were not particularly proficient naturally).

6.1 Would their children be automatically good runners? Why?

6.2 If the children of this family practiced hard over several generations would you get automatically fast runners in about 200 years? Why?

Questions # 8.1 and # 8.2 were drawn from Kargbo *et al.* (1980) to probe students' ideas about the relationship between the heights of children (boy and girl) and the heights of their parents.

8.1 If a tall man and a short woman have a child and this child is a boy, how tall will he be in comparison to his parents when he is fully grown? Why?

8.2 If a child is a girl, how tall will she be in comparison to her parents when she is fully grown? Why?

2. **Questions dealing with specific genetic concepts.** The rest of the questions dealt with student understanding of specific genetic concepts and principles. These questions are as follows.

Questions # 5.1, # 5.2, and # 5.3 were added by the researcher to determine student knowledge about genes.

5.1 What are genes?

5.2 If you know what genes are, where are they located?

5.3 How does a gene function in the transmission of traits?

Questions # 7.1 and # 7.2 (pretest) were drawn from Thomson and Stewart (1985) to probe the knowledge about monohybrid cross including the segregation and recombination of alleles.

In garden peas, green pod color is dominant to yellow.

7.1 What are the genotypes of each possible gamete produced by a pea plant that is heterozygous green pod? Explain why.

7.2 Give the resulting possible genotypes if a pea plant that is heterozygous is crossed to a pea plant that is homozygous green pod. Explain how you get the answer by making a diagram representing chromosomes and genes which are involved in the problem.

(Post test questions were modified as follows:) In beetles, wings with spots are dominant to wings without spots.

7.1 What are the genotypes of each possible gamete produced by a beetle that has unspotted wings and a beetle that is heterozygous spotted wings? Why?

7.2 What are the possible offspring genotypes of a cross between the beetles on question 7.1? Explain how you get the solution by making a diagram representing chromosomes and genes which are involved in the problem.

Questions # 9.1 and # 9.2 (pretest) were drawn from Stewart and Dale (1989) to determine student knowledge about dihybrid cross including the segregation and recombination of alleles.

In beetles, wings with spots are dominant to wings without spots, and long antennae are dominant to short antennae.

9.1 What are the possible offspring genotypes of a cross between two beetles which have unspotted wings and are heterozygous for antennae?

9.2 Explain how you get the solution on 9.1 by making a diagram representing chromosomes and genes which are involved in the problem.

(Post test questions were modified as follows:) The gene for black fur is dominant to the gene for white fur and the gene for rough coat is dominant to the gene for smooth coat.

If the results of a different cross of guinea pigs are 21 black-rough, 6 black-smooth, 8 white-rough, and 2 white-smooth.

9.1 What are the most probable genotype of the parents? Why?

9.2 Explain how you get the solution by making a diagram representing chromosomes and genes which are involved in the problem.

Questions # 10.1, # 10.2, and # 10.3 (pretest) were drawn from Thomson and Stewart (1985) to probe student understanding of the terminology: "alleles," "haploid," and "diploid."

In beetles, wings with spots are dominant to wings without spots, and long antennae are dominant to short antennae. If the wing texture gene and the antenna length gene are on different chromosomes.

10.1 In this problem how many alleles does each gene have? What are they?

10.2 How many alleles for each of these traits are present in a diploid cell? Why?

10.3 How many alleles for these traits are present in any gamete cell? Why?

(Post test questions were modified after Oram and Kaskel, 1983 as follows:) Suppose that on Mars there exist creatures with three genes controlling hair color. The allele for green hair (H^g) and the allele for purple hair (H^p) are incomplete dominant and each is dominant to the allele for orange hair (H^o). Assume that inheritance of traits on Mars occurs the same way as on Earth.

10.1 In this problem how many alleles does each gene have? What are they?

10.2 How many alleles for this trait are present in a diploid cell? Why?

10.3 How many alleles for this trait are present in any gamete cell? Why?

Questions # 11.1, and # 11.2 (pre test) were adapted from Oram and Kaskel (1983) to probe student understanding about multiple alleles.

In the ABO blood group system in humans, the alleles I^A and I^B are incomplete dominant and each is dominant to i.

11.1 If a child is born with blood type A and the mother has type O blood, list the possible genotypes of the father. Explain your choice.

11.2 List the genotypes that the father cannot be. Explain why.

(Post test questions were modified as follows:) Suppose that on Mars there exist creatures with three genes controlling hair color. The allele for green hair (H^g) and the allele for purple hair (H^p) are incomplete dominant and each is dominant to the allele for orange hair (H^o). Assume that inheritance of traits on Mars occurs the same way as on Earth.

If an offspring is born with purple hair and the mother has orange hair,

11.1 List the possible genotypes of the father. Explain your choice.

11.2 List the genotypes that the father cannot be. Explain why.

These questions were used to determine student alternative conceptions and whether conceptual changes were occurring. The questions were given in each of five different sessions as follows.

Session I was given two weeks before the instruction of heredity unit. The tasks consisted of concept mapping (Q # 1) and Questions # 2 to # 5.

Session II was given before the instruction of monohybrid cross. The tasks consisted of concept mapping and Questions # 6 to # 8.

Session III was given before the instruction of dihybrid cross. The tasks consisted of concept mapping and Questions # 9 to # 11. Questions # 7.1 and # 7.2 were post-tested during this session because the tasks would be too many to be post-tested during Session IV.

Session IV (post test) was given at the completion of the unit instruction. The tasks consisted of all the questions given in Session I through Session III except Questions # 7.1 and # 7.2. Some questions were modified but still parallel to the original questions. This session aimed at probing students' alternative conceptions and conceptual changes.

Session V (retention test) was given four months after Session IV was administered. Because the heredity unit was taught at the end of the semester, the retention test was given at the beginning of the first semester of the next school year. The tasks were identical to those used in Session IV including Questions # 7.1 and # 7.2 used in Session III.

The results from session I, II, III were expected to show preconceptions held by students before formal instruction of specific topics. The data from Session IV were expected to show the alternative conceptions which arise as a result of the formal instruction and conceptual change that might be associated with instruction. It is anticipated that the data from session V would indicate the stability of students' conceptions after a period of time.

Interview questions. Two interviews were performed with selected students before and after the unit of instruction. The students were selected on the basis of their responses to the first session of written tasks. During the interview they were asked to respond verbally to questions aimed at probing into the reasons for the responses they gave during the written tasks.

The interviews were intentionally loosely structured to allow the students' responses to guide the questions. The questions used were those questions which enabled the researcher to determine areas where the students had alternative conceptions and to encourage the students to expand upon their responses. Examples of the questions used, as suggested by Stewart (1982b), are as follows:

"How do you know that ...?"
"Why did you think / do that ?"
"Could you explain more about ...?"
"Is there any reason why you ...?"
"Is there any relationship between ...?"
"Was the unit similar to what you usually do in science or was it different ?"

"Did you change your ideas about heredity during the unit ? Was it hard to change your ideas ?"

These questions were incorporated whenever possible during the interviews. The interviews were recorded on audio-cassette tape.

Classroom observation sheets. Observation sheets were not structured in advance. The researcher and a second observer (a research assistant) made general notes about what was happening in the classroom during the visits. However, the observations focused on classroom activities, teacher's questioning patterns, the responses to students' answers and explanations, students' responses, and both student-teacher and student-student interactions. The observation also focused on the behavior of those students who participated in the interviews.

All the lessons presented by each teacher were audio-recorded and transcribed. These transcriptions along with observation notes and teacher prepared lesson plans were used in data analysis.

The second observer was involved to improve the reliability of the observation process.

Establishing validity and reliability. Validity and reliability were carefully considered in this study.

The Thai-version of written tasks was translated by the researcher. One associate professor, who was also involved in evaluating the content validity of the tasks, helped appraise the translation for accuracy.

The task questions written in Thai language were given to four subject-matter experts in the field, two associate professors who specialized in biology education and two biology school teachers who had experience in teaching the heredity unit, to insure content validity.

In scoring concept maps and responses, the researcher and research assistant evaluated the tasks independently using a scoring key (see Appendices 2 and 3). The results were compared and any disagreements were resolved through discussion.

Classroom information data were collected by means of multiple data collection methods. According to Webb (1970), internal validity can be provided by this triangulation of the between-method types. This study uses multiple methods of observation, field notes, informal interview with participating teachers, and transcriptions of audio-taped lessons.

As mentioned, a second observer was involved to improve the reliability of the observation process. After each observation, the researcher and the research assistant would come together to prepare a set of field notes based upon the notes taken during their observations. The field notes were given to the teachers after the completion of unit instruction for validation. They were invited to make any additions, deletions, or revisions to those field notes.

The researchers. The second phase of data gathering in this study was classroom observations and interviews aimed at probing into explanations and clarification of students' responses to the previous written tasks. It is important for the researchers to have background in biology to present appropriate interview questions.

The researcher had been an assistant professor in the field of science education at the Faculty of Education. Most of her 20 year teaching career had been spent in teaching biology at the Demonstration School as well as the science methods courses for education students and supervising science student teachers. Also, she has been studying English as a foreign language since she was in Mathayom One (the fifth grade). Thus she has enough background to translate all the data collected in Thai language into a valid English language version.

The research assistant who was involved in many activities throughout the research process: interviewing, classroom observing, and scoring the tasks, had been an associate professor in the field of science education in the same institution as the researcher. Her 15 year teaching career had been divided between teaching at the secondary school and university levels. She had taught secondary school general science and biology for several years before becoming a faculty member. Since the beginning of her teaching career she also had served as a cooperative teacher for science education student teachers. She volunteered to participate in the study.

Unit overview. The content and learning objectives for the unit of all participating classes were based on those outlined in the Teachers' Guide (IPST, Thai Ministry of Education, 1982). Since Educational administration in Thailand is centralized, all schools throughout the country must use the same curriculum authorized by the Ministry of Education. The sequence suggested in the guide is as follows.

1. Characteristics of living things and variation
2. Can traits be transmitted from one generation to later generations ?
3. Patterns of heredity
4. Dominance and recessiveness
5. Genotype and phenotype
6. Monohybrid cross
7. Dihybrid cross
8. Incomplete dominance
9. Alleles and multiple alleles
10. Heredity and environment
11. Polygenes

The unit under study was taught in a last separate chapter preceded by the units of reproduction and development. The teachers' guide suggests that this unit be taught for eight periods (55 minutes/period). The bulk of the unit focuses on genetic problem solving. The presentation of activities include discussion, some experiments, and problem solving.

Unit development. The designed instructional unit for Class A was composed of eight lessons of fifty-five minutes each. These lessons were planned cooperatively by the researcher and the teacher. The purpose in developing the approach was to correct students' alternative conceptions. This view of learning assumes that students' ability to learn and what they learn depend on their experience and their current conceptions. People with different conceptions will see things differently. They cannot see what they cannot conceive because seeing is something they do with ideas as well as sense (Strike and Posner, 1985).

According to Hashweh (1986), several factors exist in classrooms that affect a resistance to conceptual change.

1. Teachers are unaware of students' conceptions.

2. Evaluation methods do not capture preconceptions or assimilation of new knowledge into existing conceptions.

3. Preconceptions are not addressed even when revealed by students' answers. Teachers are not critical of answers revealing preconceptions.

For conceptual change to occur, Strike and Posner (1982) suggested that teachers should spend a portion of their time in diagnosing and correcting errors in student thinking.

Therefore in designing and applying the instructional strategies, the researcher and teacher A developed lessons with the view that scientific conceptions should develop from alternative conceptions previously held by the students.

To promote conceptual change in students, Posner *et al.* (1982) suggested four necessary conditions.

1. Students must become dissatisfied with their existing conceptions in that their ideas cannot explain the phenomenon.

2. Students must achieve a minimal understanding of the appropriate scientific conception so that they are able to apply it as an explanation to the event.

3. A new conception must appear plausible. It must have the capacity to solve the problem which their previous conception failed to explain and it must fit with other knowledge and experience.

4. A new conception must be seen as useful in a variety of situations.

The basic strategy used in the lesson plans was guided by the above theories and the sequence of teaching/learning activities was predominantly based on a constructivist teaching sequence suggested by Driver and Oldham (1986):

1. First, ask the students to make their ideas explicit. A list of alternative conceptions revealed in students' responses to the tasks is used as a guideline to establish a situation where students are required to explain or make predictions about the situation.

2. Individual students present and discuss their ideas in small groups or to the class. The exchange of ideas will provide the opportunity for students to realize that there can be different notions that explain the same phenomena. Whenever it is

po ible, the students will be brought to situations of cognitive conflict. Typically, students become dissatisfied with their current ideas as a result of these discussions.

3. Convince the validity of these ideas through the implication, then the teacher presents and explains the scientific view. In further discussions, the students are provided opportunities to compare similarities and differences of their ideas with the scientific concepts.

4. Give students the opportunity to use their developed ideas in a variety of situations so that the new conceptions are seen to be useful. A worksheet is given to the students at the end of each lesson for this purpose. This exercise enables each student to become aware of his or her own existing ideas and of the need to assimilate them with the new scientific principles they are learning.

The teaching/learning activities are summarized in Appendix 5.

The Data Gathering Process

The researcher approached informally three biology teachers, then asked for permission in writing from the Deans of the Faculty of Education and the administrators of the other two participating schools. The study was conducted during November 1990 through July 1991.

Written tasks. All students of the three selected classes were asked to participate in normal classroom instruction during which the unit of heredity was taught by their usu achers. They were informed that they would be required to respond to five different sessions of tasks, their classroom would be observed during the unit instruction, and some of them would be interviewed.

Two weeks prior to instruction of the genetics unit, the researcher gained permission to use 30 minutes at the end of the biology class to explain concept mapping techniques and provide examples (See Appendix 4). During the next regular biology class, the students responded in writing to the first session tasks. They were allowed to complete the tasks without time limits. The average time to complete the tasks was 50 minutes.

The second and third session tasks occurred during lunch time or after school due to the class time constraints. Some students did not take the third session tasks seriously and commented that the tasks were given too frequently and the tasks required overly specific knowledge. However, many students attempted to write down a response to each question.

The fourth session was held during the regular biology class because it was expected to require about two hours to complete. For schools which had one-hour class period, lunch hour was included to perform the tasks. Fortunately, there was a biology class before or after the lunch hour which made the two-hour period for taking the tasks possible.

The retention tasks (the fifth session) occurred early in the next semester because the unit of instruction that was studied was completed just two weeks before the final examinations for the previous semester. However, this posed some problems in that some students proceeded to colleges and were not available.

The interviews. Six students from each class were selected on the basis of their responses to the first session of written tasks. Each of these students demonstrated some interesting alternative conceptions to a specific task.

Two interviews were conducted: one prior to, and a second, following instruction of the unit. The first interviews lasted about 30 minutes and the second lasted about 60 minutes each. All the interviews occurred during the lunch time or after school. The place for interviews was initially chosen by each individual student but because of background noise, interviews occurred in the quietest available rooms.

The questions asked students to explain, give reasons, or expand on answers given to the written tasks. The conversations were recorded and later transcribed.

Classroom observations. The researcher met with each of the three teachers individually to explain the research project. They were informed about the purpose of the study and the expectations of each participating teacher including: (a) an agreement to allow his or her students to respond to the tasks and to be interviewed, (b) a willingness to be observed, and (c) a willingness to be interviewed. Two teachers were observed every class during the instruction of the genetic unit. Teacher C was observed only at the first class because he appeared to be uncomfortable to have an "expert" sitting in on his presentations. However, he was still willing to participate in the study and preferred to be audio-recorded. The researcher decided to keep his participation because it might be a more "natural" setting than having an outsider sitting in on the class sessions. Teacher C volunteered to converse with the researcher about the transcriptions and the teaching after each class.

Each teacher was given the results of his or her students' responses to the tasks for each session but discussion about the results in relation to planning instruction occurred only with teacher A.

During each teacher's presentation, the researcher and a second observer sat in each corner at the back of the room taking notes. When the students worked in small groups (most common in Class A), the researcher and the other observer moved around the room talking with students, observing their work and listening to their discussion. After each class, the observers discussed their field notes and a set of the resultant field notes was given to each teacher for validation.

Treatment of the Data

The following analyses were used in the study:

Scoring of concept mapping. Students' concept maps were evaluated independently by the researcher and a research assistant using a scoring key. The criteria for scoring was modified from Stuart's (1985) scoring scheme (see Appendix 2A). The results were later compared and discussed in arriving at the final scores. However, the results came up with generally the same scores. The student results were tested to determine whether there were any statistical differences among the three classes.

Scoring of task items. Student responses to each task were grouped according to the types of reasons offered. The results were summarized and tabulated for descriptive purpose.

The responses were also classified using the concept evaluation scheme adapted from Westbrook and Marek, 1991 and 1992 (See Appendix 3). The scores were given to each category as follows.

Complete understanding	=	3	points
Partial understanding	=	2	points
Partial understanding with specific alternative conception	=	1	point

Specific alternative conception	=	0	point
No understanding	=	0	point

The researcher and a research assistant categorized the tasks independently, then compared and discussed their grades to arrive at the final decision.

The mean scores were tested using series of ANOVA's and MANOVA's to determine the effects of the different instructional strategies on students' conceptual change.

Finally, the responses of individual students to the four tasks were compared and tabulated for the purpose of describing any students' conceptual changes. The written tasks of the fifth session were analyzed to determine the stability of students' conception.

Transcriptions and accounts of interviews. All interviews were audio-recorded and transcribed in totality. The comments which revealed students' alternative conceptions were then translated and presented as examples of the conceptualizations held by students.

Transcriptions and accounts of classroom observations. The purpose of the classroom observations was to describe approaches which were implemented by the teachers. The recorded tapes of classroom instruction were transcribed in totality. These transcriptions, field notes, teacher prepared lesson plans, and notes taken from informal interviews with teachers were re-read and analyzed. The data were then summarized and classified into each of the following: (a) general class format, (b) teacher behavior, and, (c) student behavior. Some excerpts were translated and presented to support the interpretations.

Chapter IV

Data Presentation and Analysis

Introduction

This chapter presents the data of this study. Classroom observations are used to describe the approaches implemented by the three participating teachers. Each teacher from Class B and Class C was responsible for the teaching of self-developed lessons and the teacher from Class A used the cooperatively-designed lessons which focused on correcting alternative conceptions. For the students' conceptions, the responses of each student to the tasks prior to and after instruction are compared item-by-item for the three classes. Further revelation of the conceptualizations held by the students are determined from the interviews. Pretest and posttest results of students' responses to the task items are compared in order to determine changes in the students' viewpoints and the effects of the two different instructional approaches identified as conventional self-developed teaching approach and cooperatively-designed teaching approach. The retention tests administered after a period of 4 months are used to determine memory decay in students.

Analysis of Classroom Situation

The purpose of this section is to identify patterns of teaching strategies and some of the differences in emphasis among the three teachers during the unit instruction. A summary of class activities at each school are included in Appendix 5 to illustrate details of activities in the classroom.

Classroom Settings

Each of the teachers' analyses and interpretations is based on a transcript of classroom presentations, field notes, and informal interviews with the teacher. Only some transcriptions are included in the results of the analysis due to the massive amount of materials to be transcribed and translated from Thai-version transcripts. More details of classroom activities can be found in Appendix 5.

Each participating class was in a large metropolitan secondary school which was ranked to be the best academic school in the region. Class A was in a demonstration school attached to the Faculty of Education, Khon Kaen University, which offered kindergarten through Mathayom Six (grade twelve). The other two classes (B and C) were in public schools attached to the Ministry of Education. Each school offered Mathayom One (grade seven) to Mathayom 6 (grade twelve). Each participating teacher conducted all the classes in a laboratory where students sat in groups of six to eight.

Class A. A conceptual-change approach (a cooperatively-designed teaching approach) was intended to be implemented in Class A. The class size was 35 and it was one of the two Mathayom Five (grade 11) classes offered in the Demonstration school.

Teacher A who participated in this orientation is in her late 30s. She received a M. Ed. with a major in science education. She started her teaching career at the Demonstration School teaching science at the lower secondary level. At the time of research she had been teaching biology for Mathayom Four and Five (grade 10 and 11) for ten years.

A month before instruction of the unit, the researcher met with Teacher A to discuss research on students' alternative conceptions and teaching strategies that facilitate conceptual change. Preliminary lesson plans for the entire unit were developed based on Teacher A's usual approach and those suggested from research studies. As soon as students' responses to the first task session had been analyzed, a more specific plan was developed using information from the analyses of students' responses. Each subsequent lesson plan was then revised and refined on the basis of experience gain from previous lessons and students' responses.

General class format. Typically, a lesson format began with a review of previous lessons. The teacher asked students for descriptions of previous lessons' conceptual content and probed their understanding. Then she exposed students' ideas about a concept under study through their explanations and predictions about phenomena. Students were encouraged to test their predictions through observations, experiments, or discussions and debate their ideas with other students in a small group. Because concepts related to genetics are invisible to naked eyes (Huang, 1988), very often, a conceptual conflict could not be established through observations but rather built on a conflict between students' ideas and previously learned scientific concepts about chromosome theories and the processes and events of meiosis which underlie the knowledge of hereditary mechanisms. Later, a representative from each group shared the idea with the class. The teacher helped them to compare and contrast those ideas in order to achieve the scientific views where supported by evidence. Students were also encouraged to apply new knowledge to everyday experience whenever it was possible. The conceptual content was later related to the content of other lessons. Therefore, learning was done through integrated fashion rather than based on isolated facts. (See details in Appendix 5A)

Teacher behavior. In the conceptual-change approach, the teacher's role is to guide discussion in which students can classify their ideas and justify them. Students are encouraged to contribute more in classroom discussions and the teacher's talk is largely dependent on what the students are saying. In modeling this role, Teacher A focused more on asking questions. Instead of direct explanation of concepts or just asking for a few facts, Teacher A frequently asked questions that challenged students' explanations. By asking "Why," "What do you think," and "What do you mean by," Teacher A was able to monitor students' thinking and supported them in developing a better understanding.

The bulk of the unit focused on problem solving, but the teacher did not just illustrate an example with all steps of the process. She usually selected some students to write out their solution steps to a particular question on the blackboard. These steps included a diagram representing chromosomes and genes involved in the problem. Students were then encouraged to compare and contrast solutions. Through discussion the class developed the most appropriate solution and applied it to the other problems.

However, it was observed that although Teacher A intended to take a passive role in discussion activities, she frequently fell into her old ways of being a knowledge transmitter. She forgot to use the strategy and relied on the text extensively. In later discussions, she blamed the curriculum and community expectation for constraining her teaching style.

Student behavior. Students played an active role in this approach. They worked and discussed ideas related to the concept under study with the teacher and other students. Instead of being mere listeners, they had more opportunities to present their ideas and share with the class. As a result, they were able to make sense of the scientific ideas at the same time that they became dissatisfied with their existing ideas.

A typical example of classroom activities in Class A is presented below. The teacher was teaching on the topic "Heredity and environment." Each student was asked in advance to bring to the class information of his/her height and the heights of his/her parents. (They had an option to use information from another family.) The students were asked to predict the heights of a son and a daughter. After four or five students presented their ideas to the class, the teacher asked each group of students to plot graphs using a set of data collected from all members of the class. The graphs were plotted separately for boys and girls against the heights of the father, the mother, and mean parental height. The verbal interaction was as follows.

Wat: The son would be taller than his father because tallness is recessive.

T: Do you mean that the son is taller than the father because you think that tallness is recessive to shortness ?

Wat: Well, I mean....nutrition and nourishment also influence the height.

T: O.K. You think that the environmental circumstances also determine the height. But can you explain more about the genes that you mentioned before ?

Wat: Usually the son is taller than the father. He (the son) is in the F_2 generation. Tallness, a recessive trait reappears. My grandfather is tall, I am tall. I am taller than my father.

T: Umm....interesting. What about you, Kai ?

Kai: The son would be taller than the mother but shorter than the father because tall is dominant.

T: Is it possible for him to be as tall as his father?

Kai: No, because his mother is short, he should be in between.

T: Well, we got two different predictions now. Does any one else have another idea ? Narit ?

....
....

T: Look at the graph, what do you think now ?

Teacher A facilitated the discussion, elicited ideas from the students and let them justify the conception. This worked fairly well throughout the instruction of the unit.

Class B. Teacher B is in her early 40s. She received a B. Ed with a major in biology teacher education. She had almost twenty years of experience teaching science at lower secondary school level as well as teaching biology at upper secondary school level. At the time of the research she had been teaching at Mathayom Five for more than ten years. The class size was 42 but since five students had not participated from the very beginning, the sample consisted of 37. These students were in the high ability group of ten Mathayom Five (grade 11) classes according to their teacher.

General class format. Teacher B used a teacher centered didactic style. She used a textbook-based teaching approach in which her explanations and questions related directly to what was written in the textbook. The lesson format predominantly began with reviewing concepts taught in previous lessons followed by a lesson exposition along with some questions, and ended with a summary and/or an assignment.

At the time of the research, Teacher B omitted all the experiments suggested in the teachers' guide. She pointed out that with time constraints and many topics to be covered, she usually used lecture mode as a medium of transmission. The unit was completed in only five, 55-minute, periods (See details in Appendix 5B) .

Teacher behavior. Most of the class time was spent on teacher explanations intervening with some questions. The questions used in Teacher B's room were those suggested at the end of paragraphs in the text. Unfortunately, there were few questions posed and most questions did not challenge students to further discussions. Students needed only to memorize a few simple facts to respond to those questions. Moreover, the questions suggested in the text rarely required the students to relate the concepts being learned to the reality of their everyday world. In consequence, many students had difficulties in responding to the questions posed in the tasks aimed to probe general public notions related to genetics.

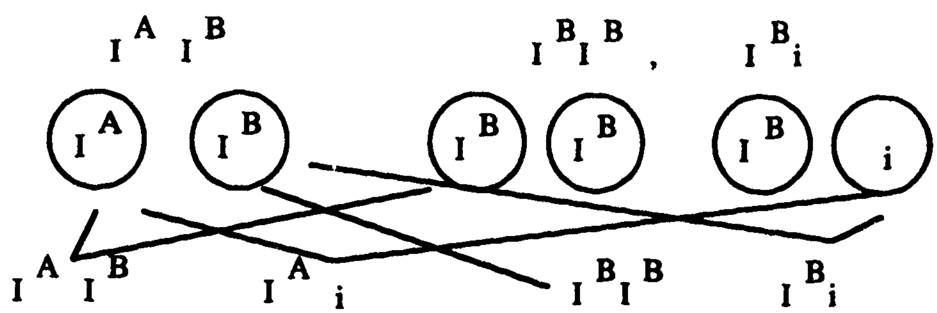
Very often, Teacher B posed a question to the class but did not wait for the answer. She answered the question herself and proceeded with further explanations of scientific concepts including those examples and details described in the textbook. Sometimes, when students responded to her question, she focused on the correct answer and related the answer to what she intended to teach. She rarely used "why" questions, so, precise answers of specific information were the elements of communication.

Teacher B focused on the problem solving process. She described repeatedly how to symbolize the genotype, how genes separated to sex cells, and the possibility of recombination. She reviewed the topics periodically and dictated notes to the students.

Student behavior. Students in Class B usually sat quietly listening to a lesson exposition. Sometimes they were required to read the textbook where related pictures, graphs, and tables were addressed. When the teacher summarized the conceptual content, students wrote down those statements in their notebooks.

Since most questions posed by the teacher required only a few simple facts, students' responses were of one or few words. They never had any opportunity to initiate questions and only once was one student asked to solve a blood type problem on the blackboard. Although there was a small error in the diagram, the teacher focused on the correct answer and accepted the solution. The problem asked for a prediction of blood types of offspring when the father had blood type AB and the mother had blood type B.

The diagram was drawn as follows:



Blood group: AB A B B

Teacher B just asked other students whether the solution was correct, then used the diagram to review the solving process.

The following classroom excerpt illustrates a typical example of classroom activities in Class B. The teacher was lecturing on the topic "Can traits be transmitted from one generation to later generations ?"

T: Traits are hereditary characteristics which can be transmitted from ancestors to the next generation. Are those characteristics which do not appear in the second generation not hereditary characteristics ?

S: Yes, they are.

T: Why ?

S: They might appear in the future.

T: Yes, they might appear in the next generations, the third, the fourth. We have to consider many generations. Does it mean that the similarity between siblings results from the transmission from the older sibling to the younger one ?

S: No, it doesn't.

T: Why ? (pause) Because the younger sibling was not born from the older one. But why do they look similar? Because fertilization is a fusion of the nuclei of sperm and egg. Chromosomes in the nuclei bring characteristics of their parents which make them look alike. They are similar not because the younger sibling was born from the older one.

Now let's go onto the topic of monohybrid cross.

Teacher B used the question posed in the textbook. Unfortunately, the text drove the discussion away from the central issue. Instead of emphasizing how characteristics pass on from one generation to the next, the question focused on who would transmit the characteristics.

Teacher B seldom provided opportunities for students to discuss or debate their beliefs. What the students had learned was a recitation of knowledge. Consequently, students had difficulty in applying the concepts as indicated in their responses to the tasks.

Class C. Teacher C is in his late 30s. He received a M. Ed in the field of science education. He had more than ten years biology teaching experience at Mathayom Four (grade 10) and at the time of the research he had been assigned to teach some Mathayom Five (grade 11) for a couple of years in addition to teaching

Mathayom Four classes. Class C size was 43 and the students were believed to be in the high ability group.

General class format. As in Teacher B's case, Teacher C used a textbook-oriented teaching approach. The predominant mode of his teaching style was a form of lecturing. He followed the prescriptions provided in the textbook and the teachers' guide. The exposition with interruptions by some questions and explanations with the aid of blackboard drawings was fairly consistent with this class.

At the time of the research, Teacher C asked the students to conduct experiments suggested in the teachers' guide by themselves outside of class hours. He mentioned that unanticipated school activities interrupted and shortened the regular schedule. Over a four week period during January and February 1991, the unit was taught to completion in six, 55 minutes, periods (See details in Appendix 5 C).

Although Teacher C asked the students to do the experiments by themselves, he seldom used the results. He ignored them when students told him that they still had not done the experiments. He used the data or examples given in the textbook to present the conclusions.

Teacher behavior. Teacher C provided more explanations and posed more questions than teacher B. In addition to those questions suggested in the textbook, he asked questions probing factual material which students had learned before. However, "why" questions were rarely posed and discussions were, similarly, rare.

Usually, Teacher C focused on the correct answers given by students. Incorrect answers were passed over or sometimes rejected without any explanation. He assumed that the correct answers indicated students' understanding of the principles. Consequently, he proceeded to the next topic and rarely provided an opportunity for students to debate or apply the concepts.

As well, in responding to students' questions, Teacher C was consistent with his style of direct teaching. The correct answer was invariably confirmed by the teacher. The function of communications was usually to provide facts and develop the concepts.

Teacher C normally taught problem solving by illustrating an example with some student help during some steps of the process. He proceeded to the solution assuming that st .dents could follow every step of the process as he commented, "If you can do it, you understand it."

Student behavior. Students usually listened quietly during the teacher's presentation. They chatted when the teacher or some students asked for a clarification or explanation. They were required to read the textbook from time to time when the teacher referred to related pictures, graphs, and tables presented in the text. They recorded key ideas, that the teacher summarized, in their notebooks.

Verbal interaction in the class was usually dominated by the teacher. A student's response was just a word or a phrase reviewing factual material. They sometimes raised some questions but mostly for conceptual clarification. When these occurred, a direct answer was given by the teacher.

A typical example of classroom activities in Class C is presented below. The teacher was teaching the terms genotype and phenotype.

T: What are genes according to what you have learned? Don't say anything that is complex. Nam, what are genes?

Nam: The parts which control hereditary characteristics of living things.

T: They control hereditary characteristics of living things. Mendel called these (genes) elements or factors. Could we see these genes?

S: No, we couldn't.

T: Mendel also stated that these genes are located in pairs. Why did he say that the genes should exist in pairs? We had talked about this that day, hadn't we?

S: Because characteristics came from the father and the mother.

T: Because the characteristics of the living things are expressed in a pair such as dimple or no dimple, detached earlobes or attached earlobes, long or short stem. From the experiments and observations, the genes must exist in pairs.

The teacher then explained how to symbolize the genes, the meaning of the genotypes and the phenotypes but one student interjected by telling the teacher that he still could not understand what the teacher meant by "existing in a pair."

T: For example, this gene (pointed at the symbol T on the black board) controls tallness and this gene (t) controls shortness. Therefore, from his (Mendel's) experiments which came up with round and wrinkled seeds, he reasoned that there are two genes which control these characteristics. Two genes are equal to one pair, right? Of course. Mendel knew nothing about cell division but he predicted or summarized from his experiments. Today we know that it (Mendel's hypothesis) is compatible with....what type of cell division?

S: Mitosis

T: His conclusions were compatible with the process of cell division nowadays called Meiosis.........

From the excerpt, it could be concluded that Teacher C used a teacher-centered style with a content-mastery approach. He focused on transferring and covering information given in the text. The interactions were dominated by teacher-initiated statements and questions and allowed little opportunity for discussions.

Teacher C paid attention to getting the right answers and was unaware of students' conceptions of the ideas. He focused on what conceptions the students should know rather than on a process of conceptualizing.

In conclusion, both teachers B and C were not aware of current research on students' alternative conceptions. Pressure to cover curriculum content made them generate classroom activities preventing them taking time to track their students' thinking and to take steps in changing alternative conceptions. Teachers just presented the concepts posed in the textbook with only a few allowing the students to talk and think about the concepts at a higher level.

On the other hand, Teacher A who had been informed about typical beliefs held by students, provided more opportunities for students to express their ideas and debate their beliefs before a particular scientific idea was presented. Students were sometimes challenged to link together those concepts being studied to explain natural phenomena or to use the newly developed ideas in a variety of situations. However, it was observed that time constraints frequently dictated Teacher A to slip into her old ways of teaching in which her explanation and questions related directly to what was suggested in the textbook and teachers' guide.

Analysis of the Tasks

The responses of each student to each task were analyzed item-by-item.

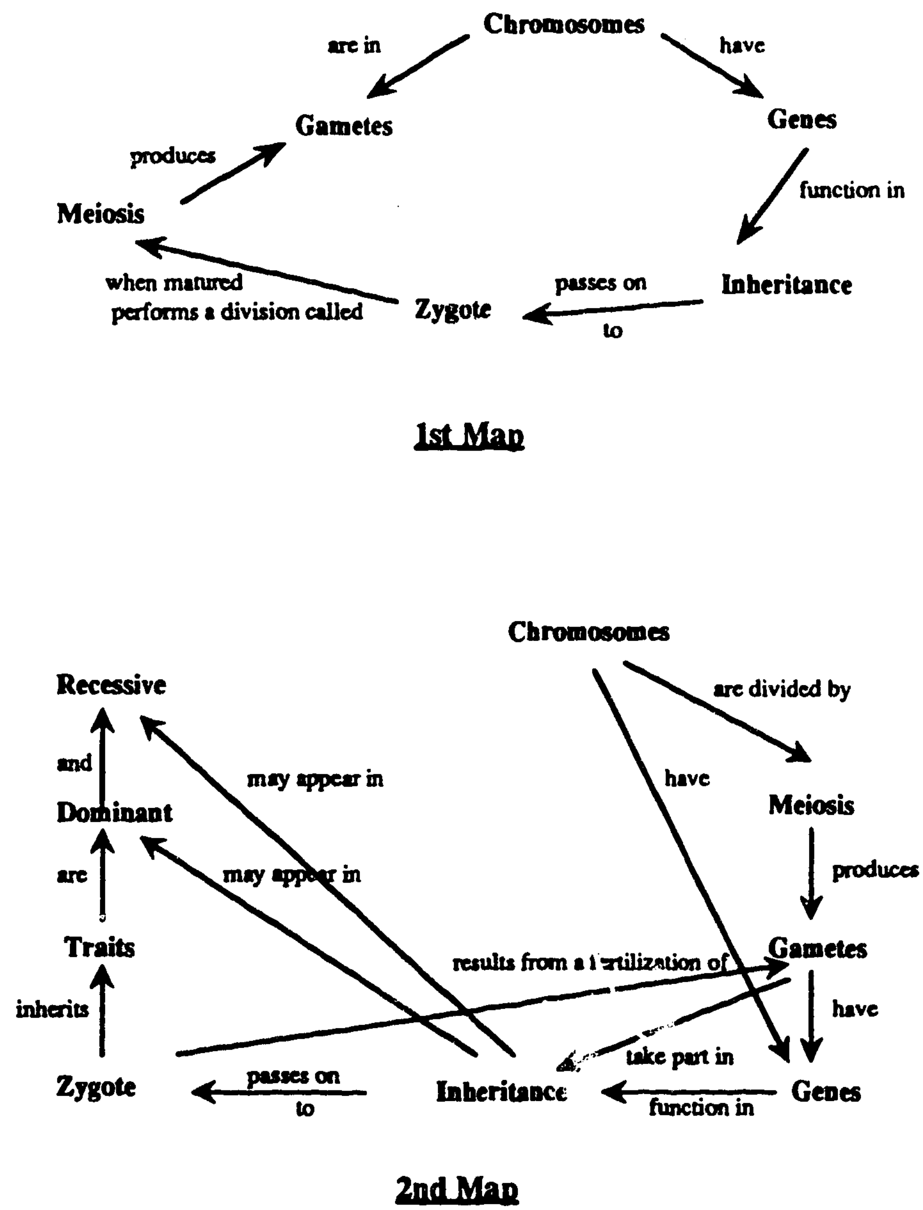
Concept Mapping (Question # 1)

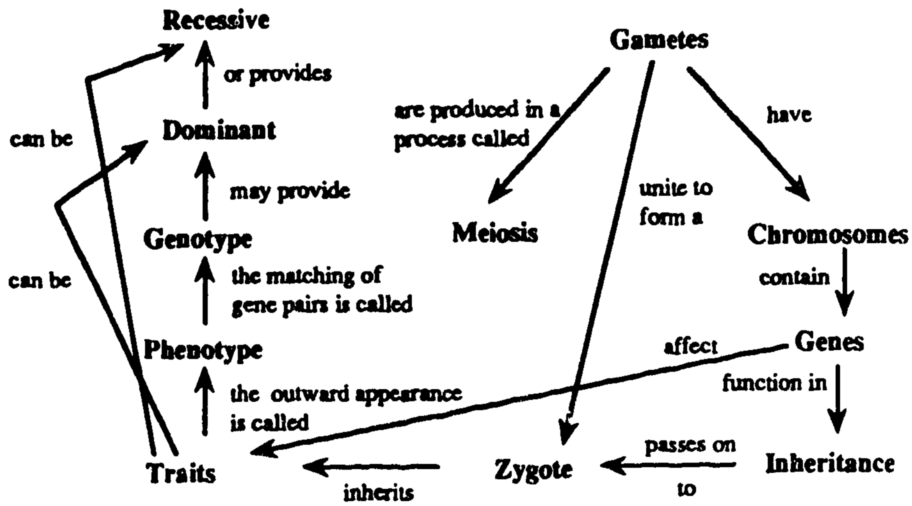
Question # 1 of each session of written tasks required the preparation of concept maps. The students were given a list of six concepts at the first session, then three concepts were added to each of the two following sessions as deemed appropriate for the objectives of the genetics lessons being taught. The fourth (the post test) and the fifth sessions (retention test) consisted of the twelve concepts which had been given at the third session (see Appendix 1).

Figures 2 to 10 are examples of the concept maps constructed by three students from each class. One of each performed better than average in the post test, and the other two were below average. These maps illustrate their development and change in conceptual understanding through the four sessions of written tasks. The concept maps constructed by these students demonstrated the complex nature of change in conceptual understanding. Although some students appeared to have a clear knowledge of relationships between the concepts given at the very beginning, they demonstrated the difficulties of integrating new knowledge received recently in classes with prior knowledge as the number of concepts increased. Some propositions persisted, but some were revised, whether improved or irrelevant. Some linkages indicated memorized responses such as the links used by Chantra from Class C (See Figure 9).

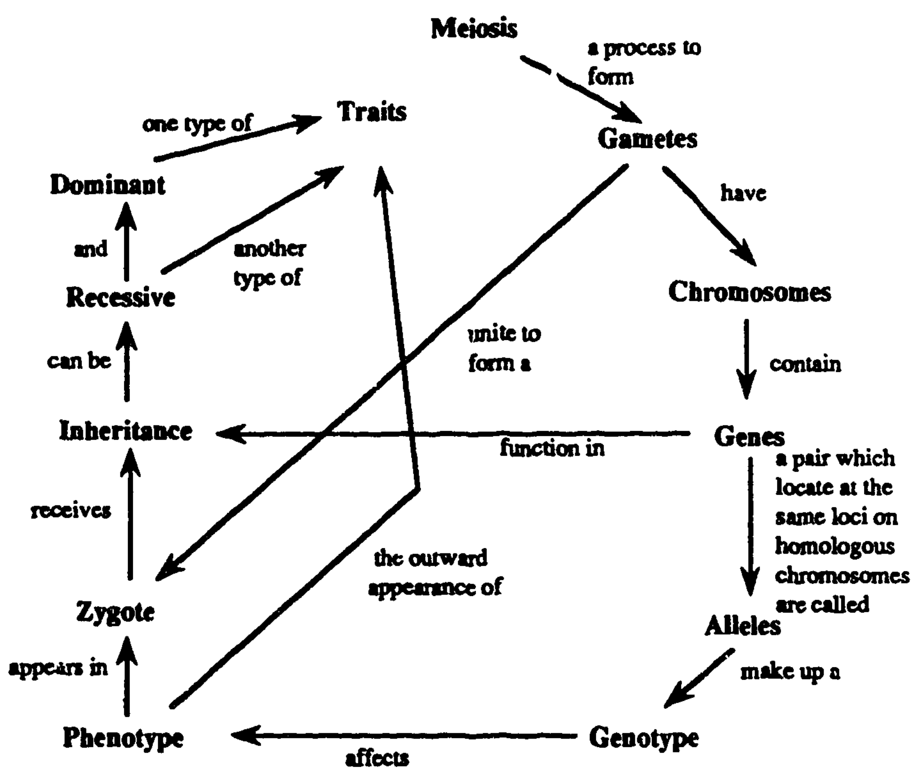
The first example (Figure 2) was drawn by Wilai, a female student from Class A, who scored above average. On the first session, her map was a cycle, starting and ending at chromosomes. Her prior knowledge appeared to be well structured concerning the relationships between the six concepts given, except that she indicated the wrong direction of linkage between chromosomes and gametes. The number and quality of cross-links increased in the second map. However, she still could not clarify her idea about chromosomes and gametes as she left blank the linkage between the two concepts. An alternative conception found in the second map was that the student conceived meiosis as a chromosomal division. Her third map indicated a better understanding of chromosomes and gametes. At this time she did not put any linkage between meiosis and chromosomes. Neither did she include the concept "allele" in the map. She could not differentiate between "phenotype" and "genotype" as well as specify the relationships between "genotype" and "dominant"/"recessive". The fourth map illustrated the benefit from instruction whereby Wilai could assimilate new information into appropriate conceptual frameworks although she still adopted a memorized definition of allele to the linkage.

Figure 2. The concept maps constructed by Wilai from Class A.





3rd Map

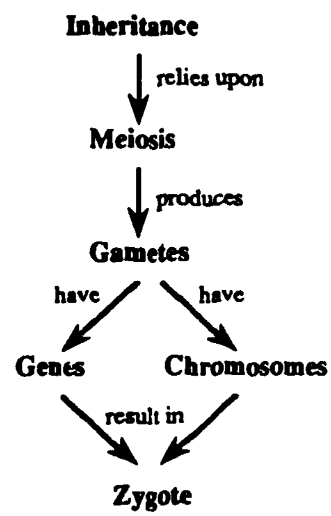


4th Map

Jinda, a female student from Class B, performed fairly successfully in concept mapping as shown in Figure 3. Her first map indicated her confusion of the linkages between zygote and chromosomes/genes. Her second map showed better understanding of the concepts with a linear addition of new concepts. She continued the hierarchical arrangement of the map in the third attempt except she put the replacement of new concepts, genotype and phenotype, under traits. She believed that traits consist of phenotype and genotype. Like many other students, Jinda did not have any ideas about allele. A major restructuring of the concepts was shown in the fourth map. There were more cross links and integration but she did not have clear knowledge about alleles, phenotype, and genotype.

Shane represents an above average male student from Class C. His maps are shown in Figure 4. He did not perform as well as the two students from other classes, but he demonstrated improvement of conceptual understanding in comparison to his initial knowledge. His verbal linkages in the first map indicated a rote-learning pattern. The propositions improved in the second map but he still could not clarify the relationships between zygote and traits, and gene and dominant/recessive. Neither could he specify linkages to the new concepts given in session III. In addition, he suggested alternative conceptions that chromosomes controlled alleles, and a genotype was genes which existed in pairs. He reconstructed the final map but still demonstrated difficulties in assimilating the concepts about alleles, phenotype, genotype, dominant, and recessive.

Figure 3. The concept maps constructed by Jinda from Class B



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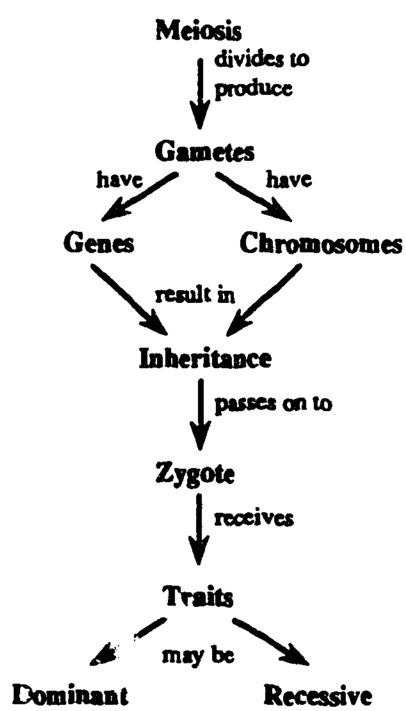

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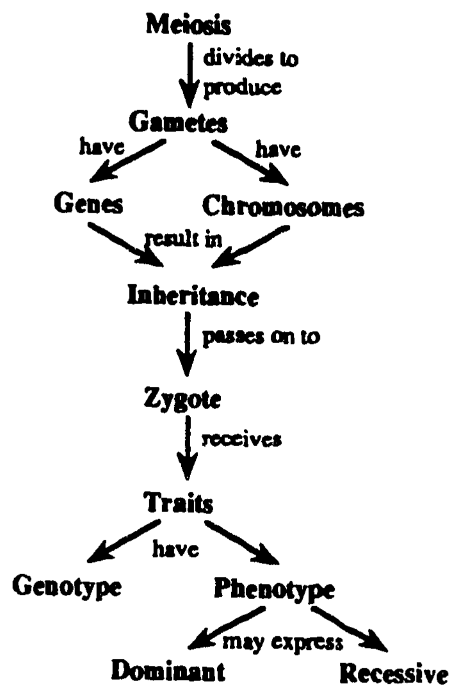

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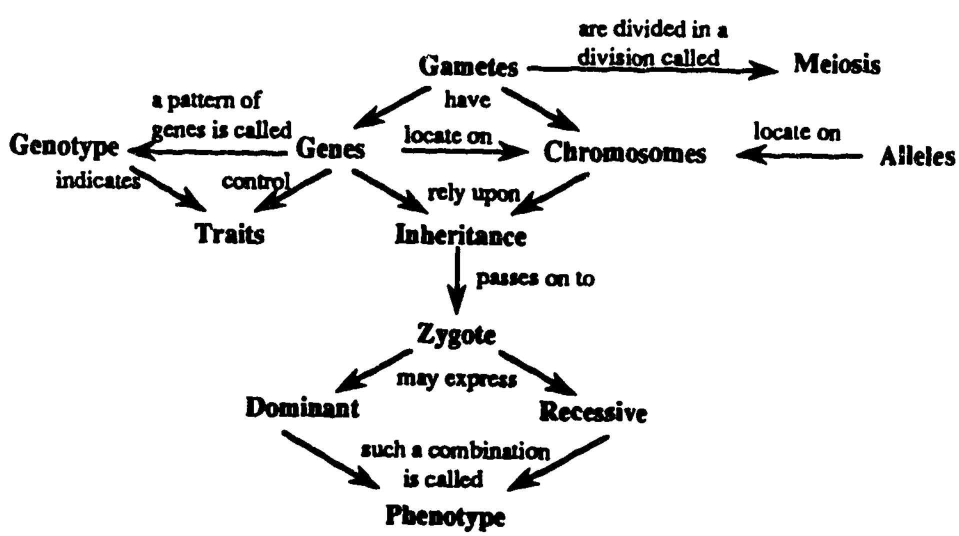
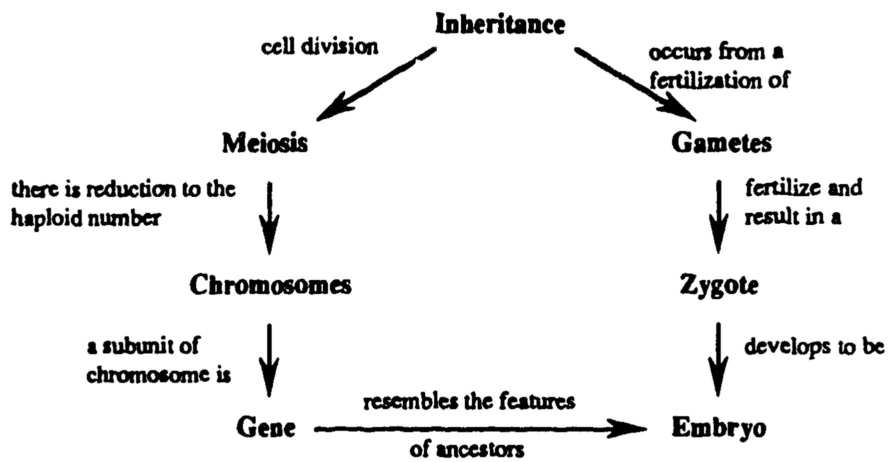


4th Map

Figure 4. The concept maps constructed by Shane from Class C.



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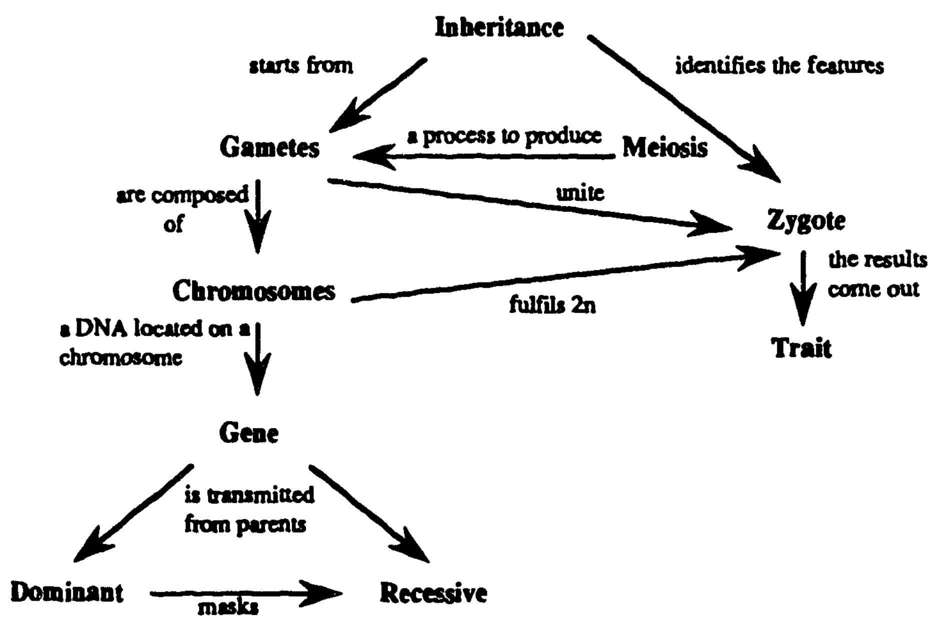

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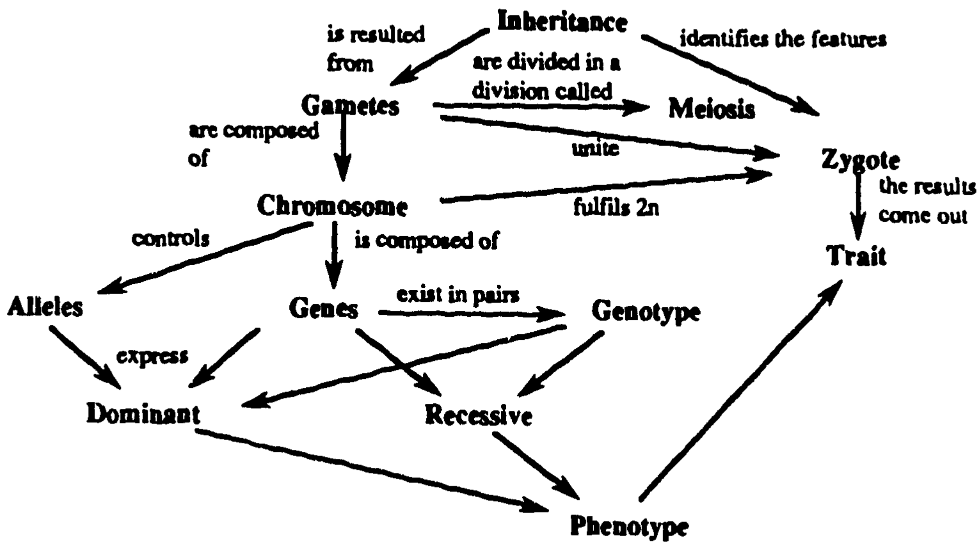
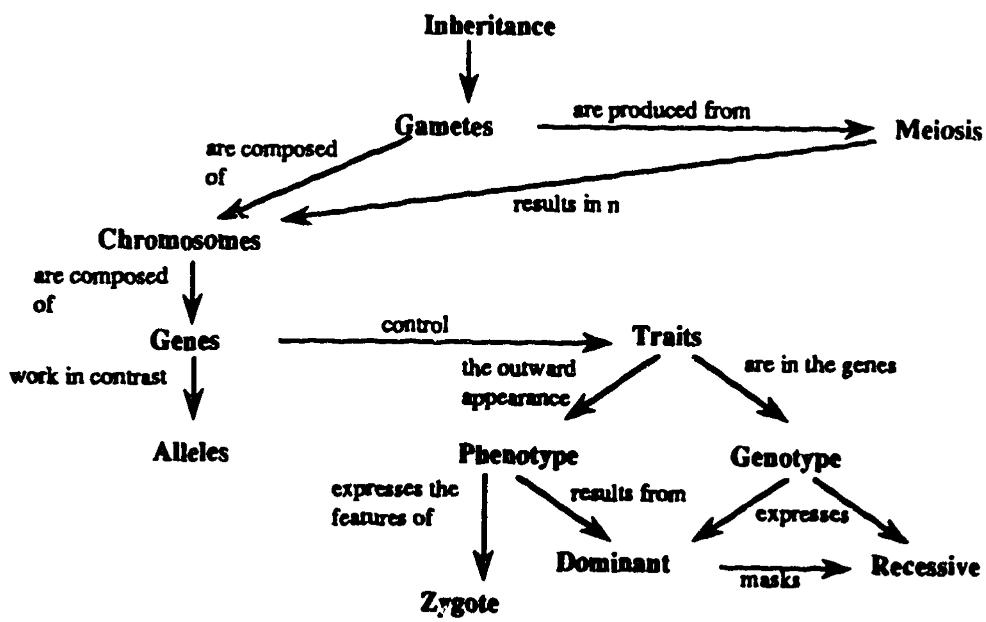


<u>3rd Map</u>



<u>4th Map</u>

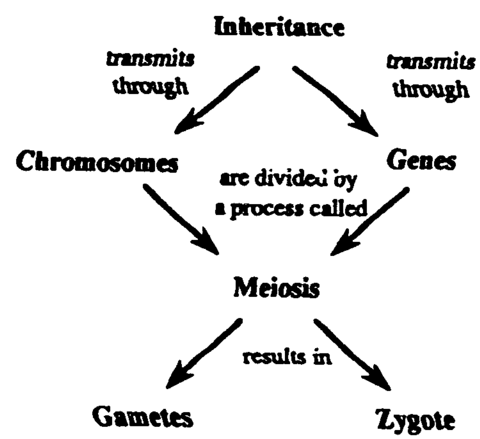
The following six sets of concept maps are examples of work done by two less able students from each class.

Figure 5 illustrates the concept maps drawn by Kane, a male student from Class A. He provided a linear pattern of integrating information. There were no cross links between any concepts in all his maps. His alternative conception that a zygote resulted from meiosis persisted throughout the learning process. Kane made no progress in his understanding of the mechanisms of inheritance.

Similarly, Charlie, a male student from Class A showed little progress in his understanding. His propositions indicated a lack of confidence in his knowledge as he modified them regularly without success (see Figure 6). Charlie could not complete the third map but performed better in the fourth one. He, too, failed to integrate new learning into his existing knowledge structure.

Chai, a male student from Class B, presented a linear structure of his conceptual frameworks. He reconstructed his knowledge every time but unsuccessfully provioed valid structure (see Figure 7). He could not identify verbal linkages between concepts and also presented some alternative conceptions. He did not understand the process of reproduction and the newly introduced concepts about inheritance. In contrast, his classmate, Laksana-a female student, showed a better network of her knowledge structure (see Figure 8). However, from the very beginning of this study she held a popular alternative conception that a zygote resulted from meiosis but improved her understanding on the fourth map. She was another student who failed to assimilate the new learned concepts about inheritance into her existing knowledge structure. Her linkages demonstrated poor understanding of the relationship between concepts.

Figure 5. The concept maps constructed by Kane from Class A.



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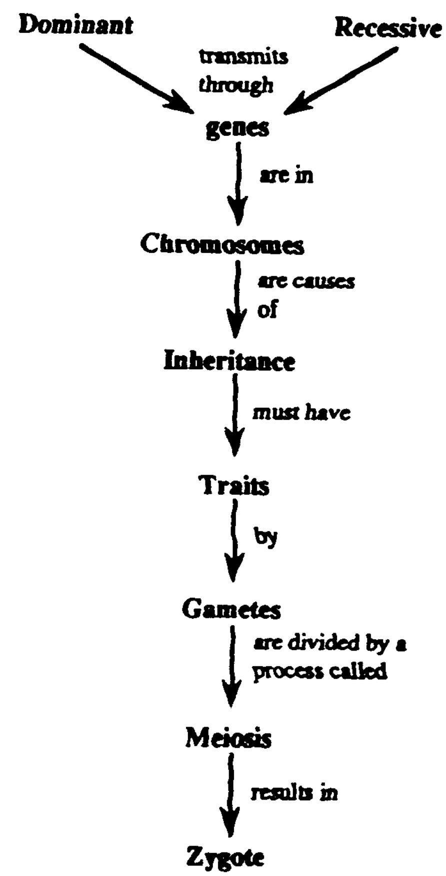

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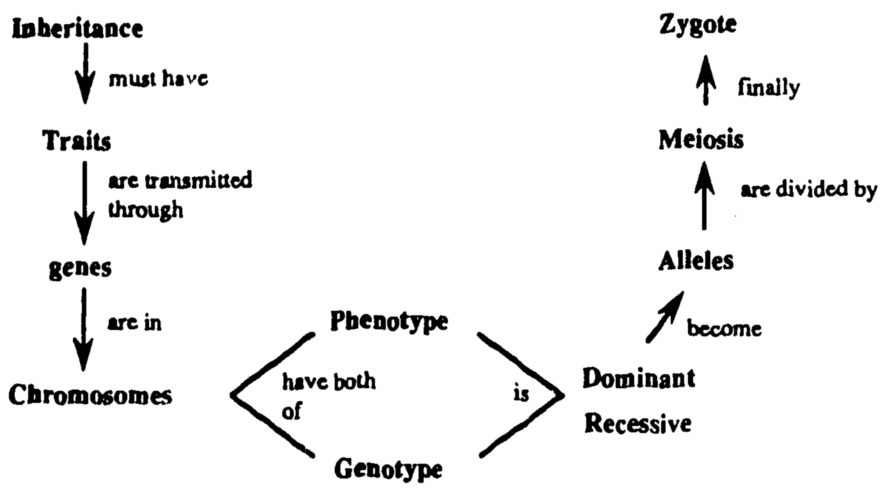

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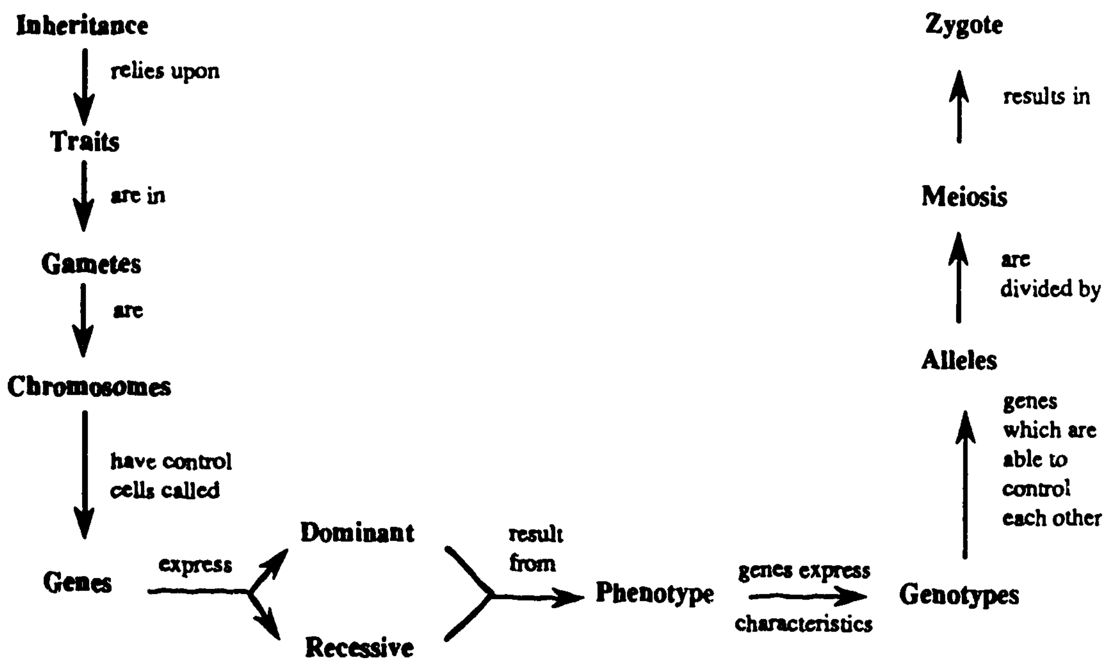
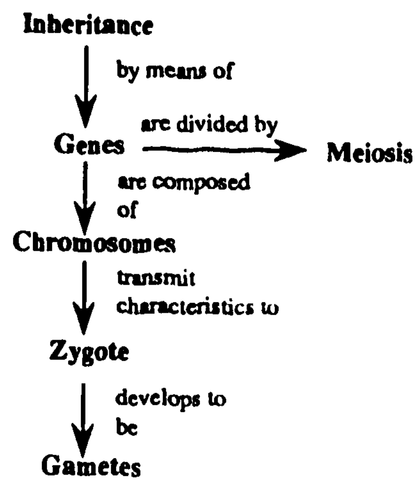


4th Map

Figure 6. The con:ept maps constructed by Charlie from Class A.



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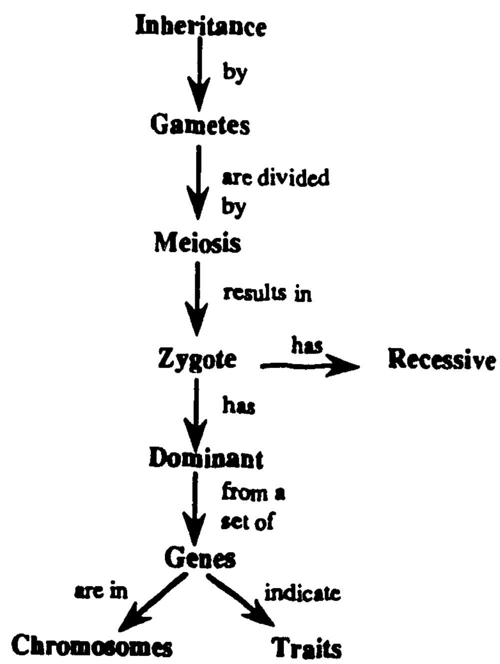

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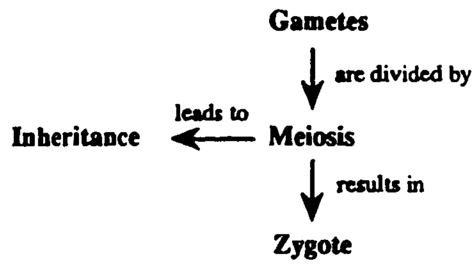

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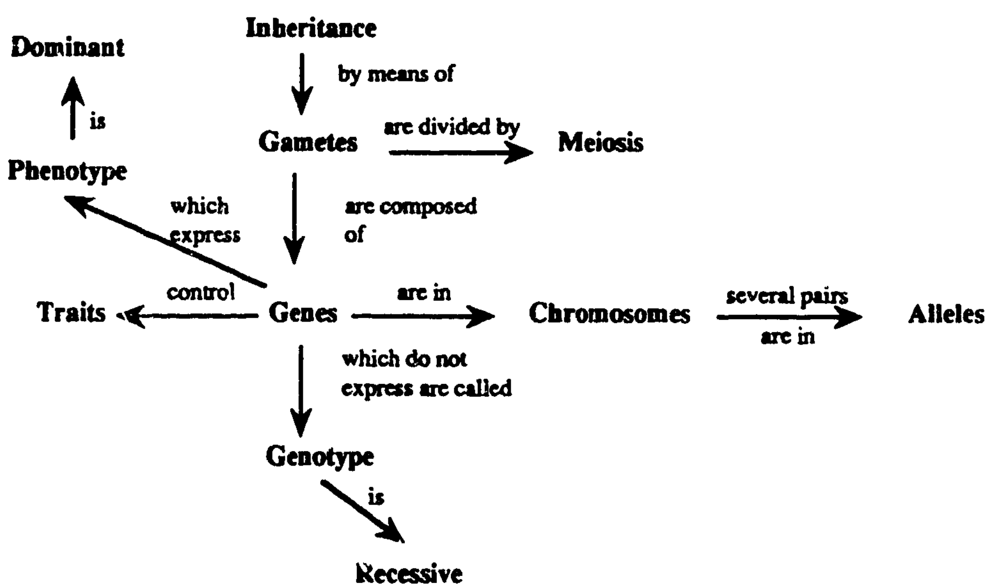
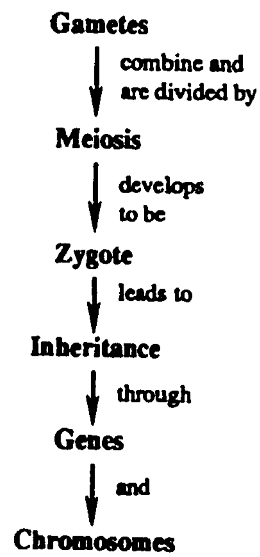


4th Map

Figure 7. The concept maps constructed by Chai from Class B



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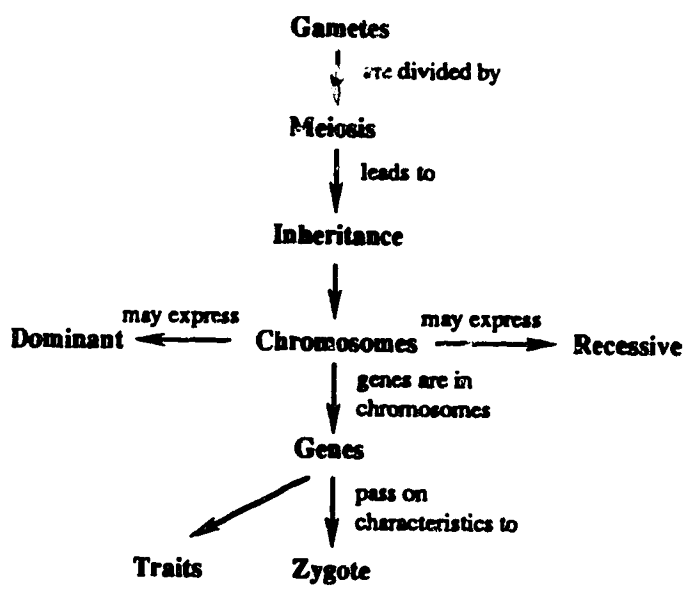

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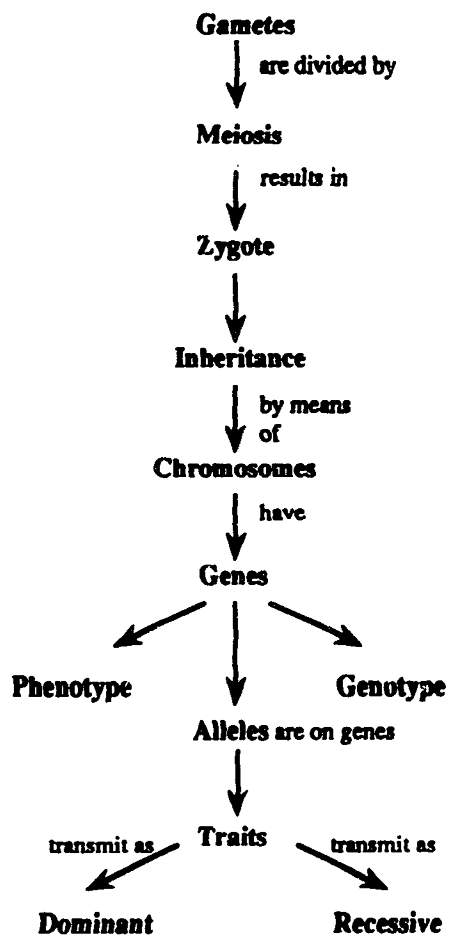

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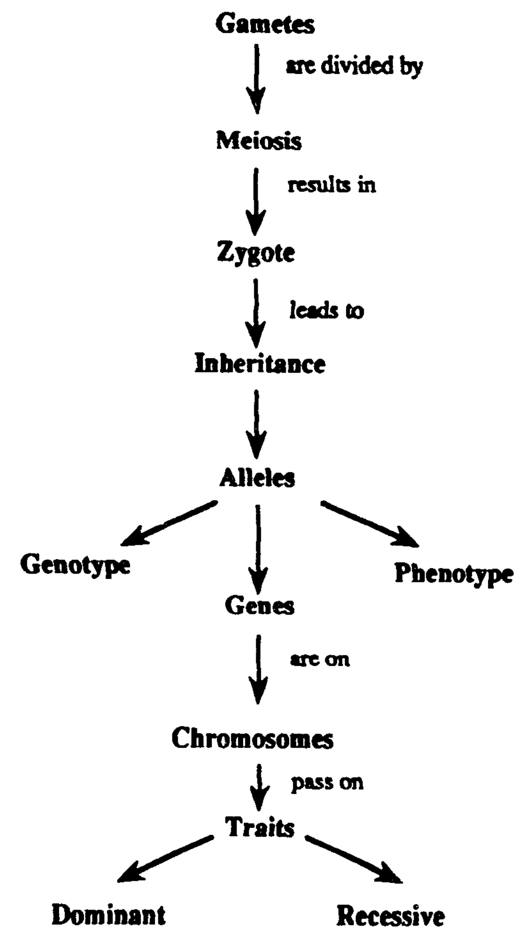
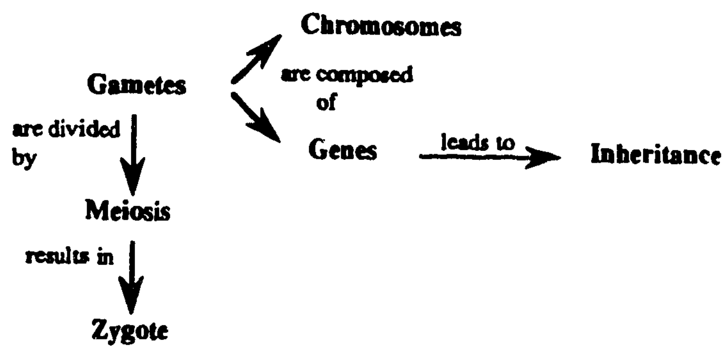


4th Map

Figure 8. The concept maps constructed by Laksana from Class B



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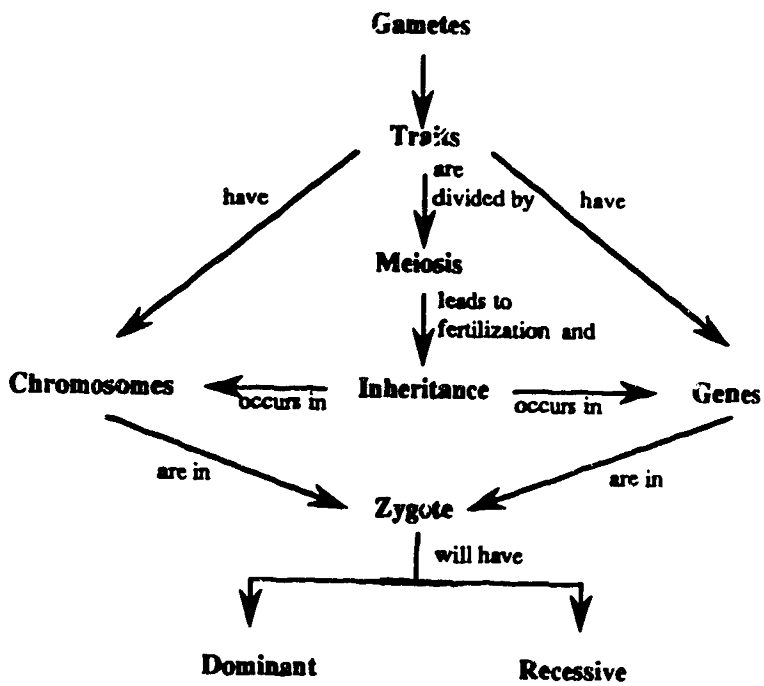

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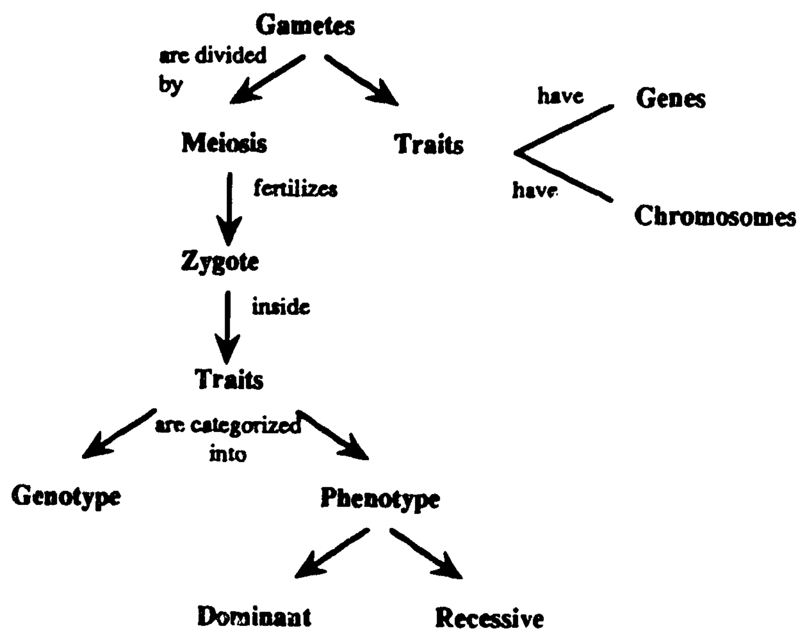

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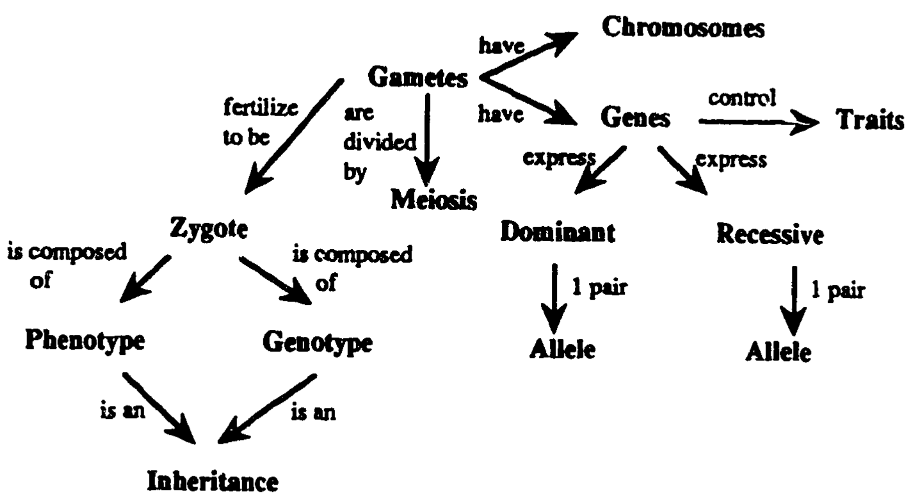
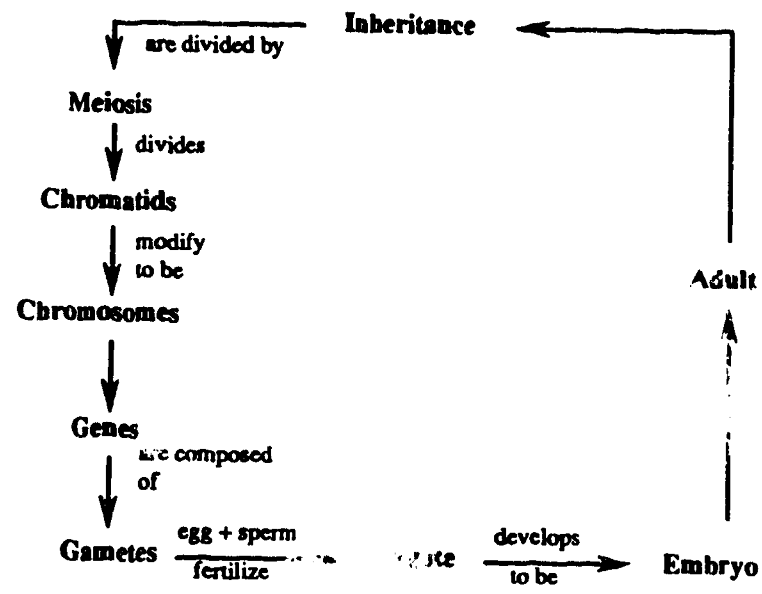


4th Map

Figure 9. The concept maps constructed by Chantra from Class C



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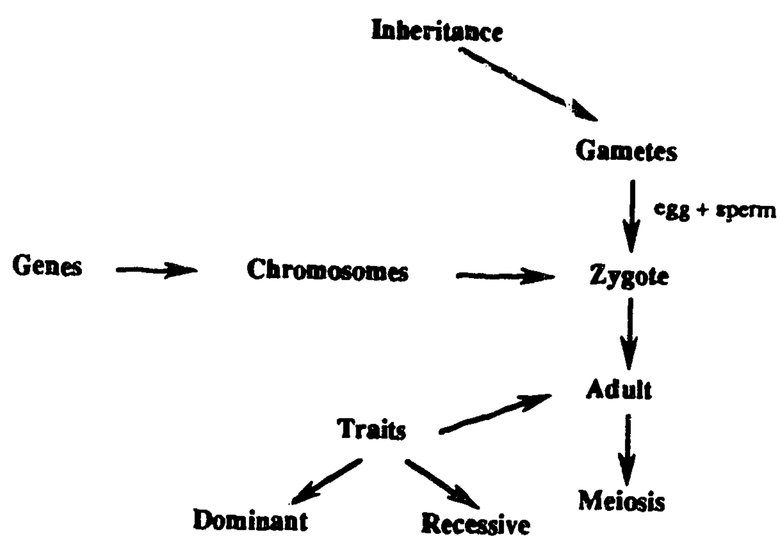

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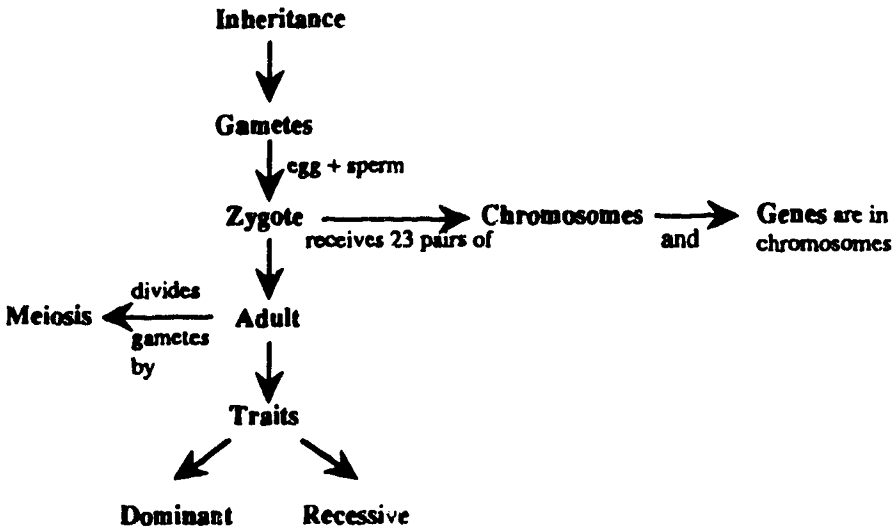

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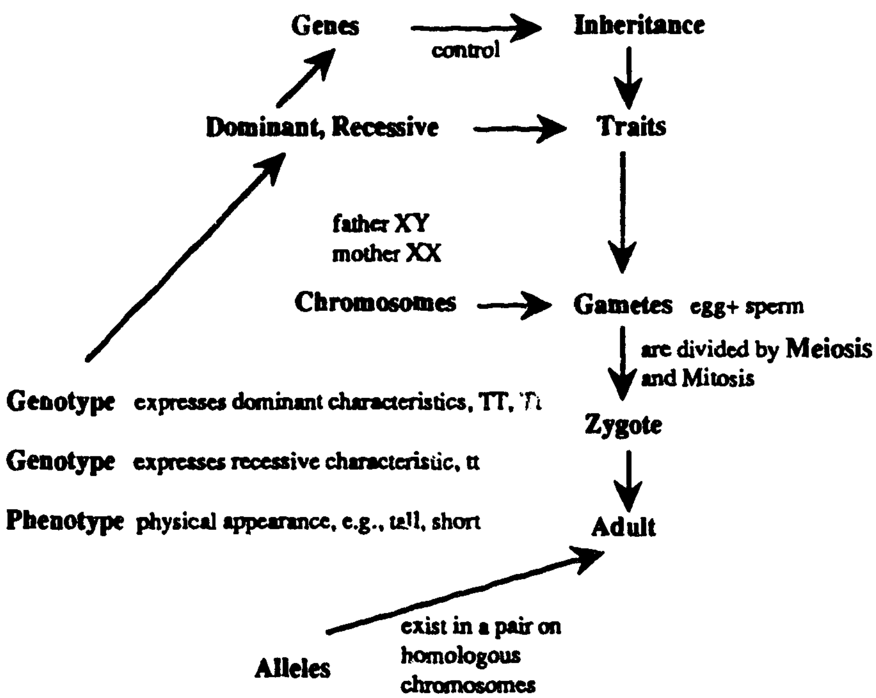
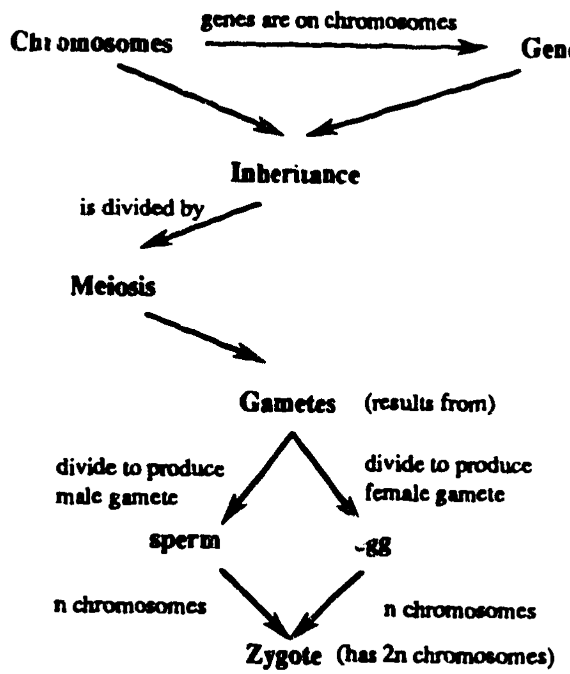


4th Map

Figure 10. The concept maps constructed by Natre from class C



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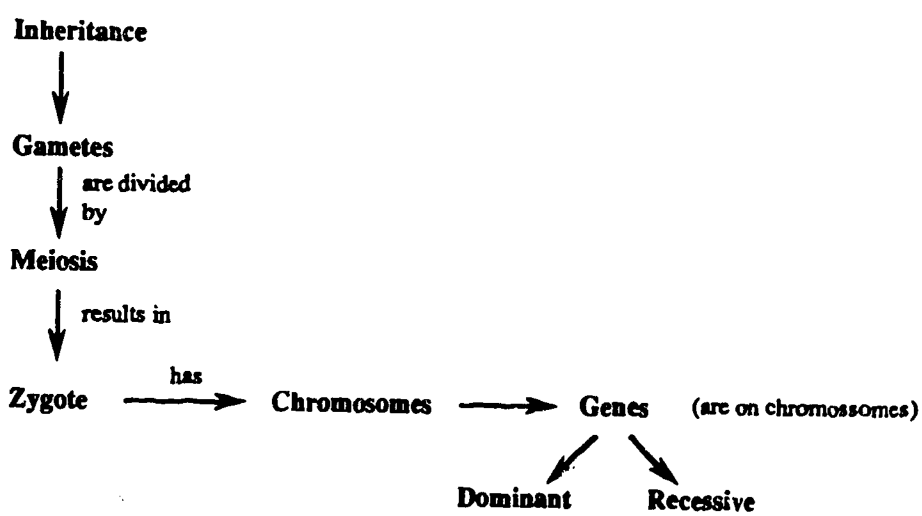

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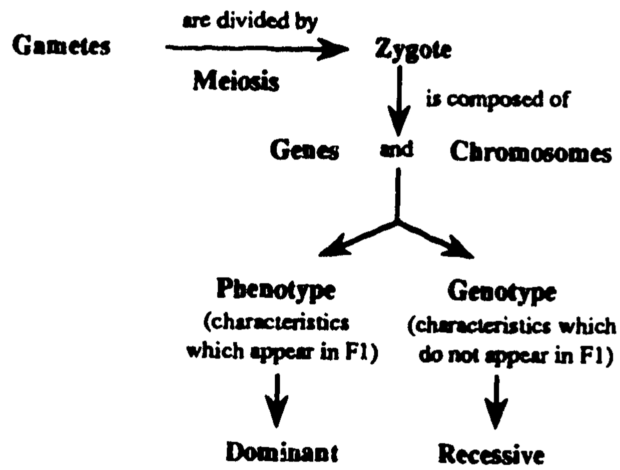

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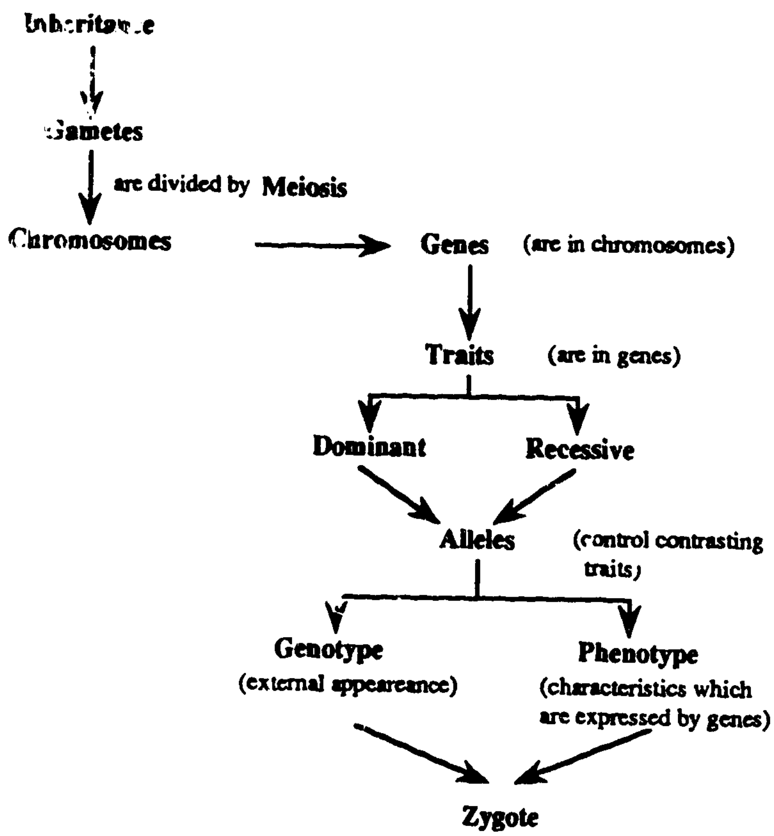


4th Map

Figures 9 and 10 are concept maps constructed by Chantra and Natre, less able female students from Class C. From the very beginning, Chantra failed to understand the relationships between inheritance and meiosis, and chromosomes and genes (see Figure 9). She was less confident of her knowledge when she constructed the second map which did not specify any verbal linkages except between gametes and zygote. She showed little improvement in conceptual understandings of chromosomes, genes, zygote, and meiosis in the third map. However, Chantra's knowledge structure became worse after the unit instruction. Her fourth map indicated a pattern of rote-mode learning as well as a regressing understanding of reproduction.

Similarly, Natre's concept mapping indicated that she held an alternative conception that gametes divided into sperm and egg. Also she could not specify a valid relationship between inheritance and meiosis (see Figure 10). Her conceptual understandings did not improve throughout the instruction, whether conceptions about reproduction or inheritance.

The nine examples described above serve to illustrate individual student thinking processes and knowledge structure. Some students showed reasonable levels of meaningful learning but others remained in patterns of rote-mode learning. Although average students from class A scored highest in every session, the results in this study indicated that the instruction, whatever the approach, was not productive in helping individual students to assimilate new information into appropriate conceptual frameworks.

Session I Tasks

Questions # 2 to # 5. Question # 2 to # 5 were given in the first session of written tasks which was held before any instruction of the genetics lessons. These questions were developed to probe students' interpretations about general public notions related to genetics.

Question # 2.1 was adapted from a group of questions developed by Kargbo *et al.* (1980). Students were presented with drawings of two dogs, then they were asked, "Suppose the tails of two dogs were cut short at a veterinary clinic when they were just two weeks old. If these two dogs later have a puppy, what will be the length of the tail of this puppy? Explain why?"

Table 1. The percentage of students' responses to Question # 2.1 before and after instruction.

Type of Responses	Percentage of Students					
	Before Instruction			After Instruction		
Answer & Reason	Class A (n=35)	Class B (n=37)	Class C (n=43)	Class A (n=35)	Class B (n=37)	Class C (n=42)
Normal tail:						
*No genetic/ gametic change.	48.57 (n=17)	59.46 (n=22)	60.47 (n=26)	82.86 (n=29)	67.57 (n=25)	76.19 (n=32)
**Parents were born with tail.	25.71 (n=9)	13.51 (n=5)	25.58 (n=11)	5.71 (n=2)	5.41 (n=2)	11.90 (n=5)
**Natural/Trait conserved.	14.29 (n=5)	13.51 (n=5)	11.63 (n=5)	2.86 (n=1)	[illegible]	2.38 (n=1)
Alternative reasons including no explanations.	0.00 (n=0)	8.11 (n=3)	0.00 (n=0)	2.86 (n=1)	2.70 (n=1)	2.38 (n=1)
Short/No tail:						
Various alternative reasons.	11.43 (n=4)	5.41 (n=2)	2.33 (n=1)	2.86 (n=1)	0.00 (n=0)	2.38 (n=1)
No reasons or answers were not clear.	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	2.86 (n=1)	16.22 (n=6)	4.76 (n=2)

* = accepted response
** = accepted response as partial understanding

Class A = a class where a teacher uses the cooperatively-designed lesson (440 minutes instruction)
Class B = a class where a teacher designs her own lesson plans (275 minutes instruction)
Class C = a class where a teacher designs his own lesson plans (330 minutes instruction)

The accepted response for the question was that the puppy would have a normal tail because there is no genetic change or no change in its parental gametes.

Table 1 summarizes students' responses to Question # 2.1 before and after instruction. Before any instruction, about half of the students in each class (48.57% in Class A, 59.46% in Class B, and 60.47% in Class C) demonstrated understandings of the difference between acquired characteristics and purely inherited traits, while some students (11.43% in Class A, 5.41% in Class B, and 2.33% in Class C) still believed that some environmentally produced characteristics could be passed on to the next generation. Although many students thought that this characteristic would not be transmitted to the offspring, their reasons were simply that it was "natural" or because the parents were born with tails (40.00% in class A, 27.02% in Class B, and 37.21% in Class C). Some students in Class B (8.11%) understood that there would be no change but one student could not explain why and the others demonstrated alternative conceptions for their explanations. Those reasons were: it was too soon for any change and tailless was recessive.

After the completion of instruction, the number of students in the post-test who answered correctly increased to 82.86% in Class A, 67.57% in Class B, and 76.19% in Class C. Nonetheless, 8.57% of Class A, 13.52% of Class B, and 14.28% of Class C retained their simplistic explanation that it was natural for rats to have tails or because the parents were born with tails. Very few students (2.86% of Class A, 2.70% of Class B, and 2.38% of Class C) demonstrated their alternative interpretation that the rat would have a tail because tailless was recessive. Only one student from Class A (2.86%) and one from Class C (2.38%) still believed that although the acquired characteristic would not be passed on immediately, it could be transmitted in the next few generations because the rats never used their tails. The rest of students, 2.86% in Class A, 16.22% in Class B, and 4.76% in Class C, did not describe their reasons or the explanations were too rounded and equivocal.

Question #2.2 was added to assess students' viewpoints about the effect of time on the possibility of inheritance of acquired characteristics. They were asked, "What would happen if tails were repeatedly cut off over several generations-what kind of puppies would you end up with? Why?"

Table 2. The percentage of students' responses to Question # 2.2 before and after instruction.

Type of Responses	Percentage of Students					
	Before Instruction			After Instruction		
Answer & Reason	Class A (n=35)	Class B (n=37)	Class C (n=43)	Class A (n=35)	Class B (n=37)	Class C (n=42)
Normal tail:						
*No genetic/gametic change.	37.14 (n=13)	40.55 (n=15)	51.16 (n=22)	54.29 (n=19)	43.24 (n=16))	54.76 (n=23)
**Parents were born with tail.	14.29 (n=5)	10.81 (n=4)	18.60 (n=8)	11.43 (n=4)	10.81 (n=4)	9.52 (n=4)
**Natural/Trait conserved.	2.86 (n=1)	2.70 (n=1)	11.63 (n=5)	2.86 (n=1)	0.00 (n=0)	4.76 (n=2)
Normal or short tail:						
*If there is a mutation.	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	5.71 (n=2)	5.41 (n=2)	2.38 (n=1)
Some genes changed	2.86 (n=1)	0.00 (n=0)	2.33 (n=1)	2.86 (n=1)	2.70 (n=1)	4.76 (n=2)
If parents are hybrid.	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	2.70 (n=1)	9.52 (n=4)
Short/No tail:						
Adjustment of genes	25.71 (n=9)	21.62 (n=8)	0.00 (n=0)	8.57 (n=3)	16.[illegible]2 (n=6)	7.14 (n=3)
"Disuse" of the tail.	11.43 (n=4)	13.51 (n=5)	0.00 (n=0)	11.43 (n=4)	5.41 (n=2)	2.38 (n=1)
Other alternative reasons.	5.71 (n=2)	8.11 (n=3)	6.98 (n=3)	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)
No reason/No answer	0.00 (n=0)	2.70 (n=1)	9.30 (n=4)	2.86 (n=1)	13.51 (n=5)	4.76 (n=2)

* = accepted response
** = accepted response as partial understanding

The accepted response for the question was that the puppy would have a normal tail because repeated phenotypic change would never cause a genetic change. Another accepted response was that there might be some changes if a genetic mutation had occurred.

Table 2 presents the viewpoints of students in responding to the question. The results of the pretest indicated that 45.71% of students in class A, 45.94% of students in Class B, and 18.61% of students in class C predicted that the puppies would have short or no tails. Only 37.14 % of Class A, 40.55% of Class B, and 51.16% of Class C gave correct responses. 14.29% of Class A, 10.81% of Class B, and 18.60% of Class C provided a simple reason that the parents were born with tails whereas 2.86% of Class A, 2.70% of Class B, and 11.63% of Class C just stated that it was natural to have tails.

The post-test results indicated a slight increase in the percentage of students giving acceptable explanations: 60.00% in Class A, 48.65% in Class B, and 57.14% in Class C. Almost the same percentage of students in Class A and Class B (14.29% and 10.81% respectively) retained their beliefs of natural or tailed-born parents as presented in the pre-test but the percentage of students in Class C declined from 30.23% to 14.28%. The students who held alternative conceptions were 25.72% in Class A, 40.54% in Class B, and 28.56% in Class C.

When compared to Question # 2.1 the number of students who believed that the passage of time had influence on the transmission of phenotypic change increased dramatically. Before any instruction, the difference of 34.28% in Class A, 32.42% in Class B, and 16.28% in Class C thought that although the phenotypic change was not inherited immediately, it might be passed on over several generations.

Also after the completion of instruction, more students in each class believed in the effect of time on the possibility of inheritance of phenotypic change. The students who believed that the rats would have no tail were shifted from 5.72% to 25.72% in Class A, from 18.92% to 40.54% from Class B, and from 9.52% to 28.56% in Class C.

The following interview quotes illustrate examples of student reasoning used in arriving at their answers. In the first round interview, Khom, from Class A, stated that the puppy of Question # 2.1 would have normal tail because "those things which will carry on this trait are still in the gametes of the parent dogs." When asked what he meant by "those things," Khom mentioned "chromosomes" with confidence. However, in response to Question # 2.2 he referred to what he had read about theories of evolution and misinterpreted Lamarck's idea to be Darwin's theory:

> I love to read. I found this evolution theory from a journal in the library, the theory of Charles Darwin, I think. It said that at the ancient time, the Giraffes had short necks, later the leaves they fed were higher up from the ground. They needed to develop their necks to stretch to reach the leaves. Their necks became longer and longer. So , I thought this principle might be put to use with the case of the puppies. The tails were cut off and cut off, it is better not to have a tail. Therefore the tails will become shorter and shorter, and finally, the puppies would have no tail at all.

Another student from class B, Phong, believed that the phenotypic change would be passed on immediately. He explained that, "It (the puppy) has inherited this trait from its parents." When asked which was the trait between normal tail of its ancestors and the short tail of the parent dogs, he asserted that, "The trait is short-tailed." Unsurprisingly, he had his reason for the effect of time:

> Well, the short tail trait had continuously passed on to the later generations, the offspring must have short tails undoubtedly.

Nam from Class C pointed out that "Short tail is a dominant characteristic inherited from the parents. The puppy will be pure short tailed." She also expanded that, "Pure short-tailed resulted from a pair of genes which are homologous, because both parents are short-tailed. If one of the dogs has long tail, it (the puppy) would be hybrid."

From the interviews, Nam seemed to know quite well about genes and had confidence that, "Cutting off tails makes the genes change." Therefore she answered that the puppies would have short tails to both questions.

After the instruction, although more students demonstrated their understanding of the difference between acquired characteristics and purely inherited traits, some students still persisted in their prior conceptions. For example:

Dam from Class A, who believed in the first round interview that the acquired characteristics could be passed on to the next few generations, retained his belief.

> Dam: The baby mice will have no tail because the genotype has changed.

Interviewer: Why did the genotype change?

Dam: Because the tails were cut short.

Interviewer: So, would the amputated limb couple produce an amputated child?

Dam: No, the child will be normal because humans and mice are not the same.

Not surprisingly, Dam also thought that over several generations the baby mice would undoubtedly have no tail because "there is an adjustment of the chromosomes."

Similarly, Anu from Class B, continued to keep his interpretation even after the instruction.

Anu: All the baby mice would have tails because their life-span is shorter than humans'. There is no continuous change.

Interviewer: And what would happen if tails were repeatedly cut short over several generations?

Anu: They would have no tail. Only continuous changes could affect the genes.

Interviewer: What makes you think like that?

Anu: From my notebook, our teacher taught that there were two changes, continuous and discontinuous changes. Only continuous change would affect the genes.

However, none of the six students from Class C who were involved in the interviews provided alternative conceptions after the instruction. For example, Nam, whose idea was excerpted in the previous section demonstrated a better understanding.

Nam: The baby mice would have tails because cutting-off tails does not affect the genes.

Interviewer: But if the tails were repeatedly cut short, what would happen to the tails after several generations?

Nam: They will still have tails because the genes do not change at all.

Interviewer: So, why is there evolution?

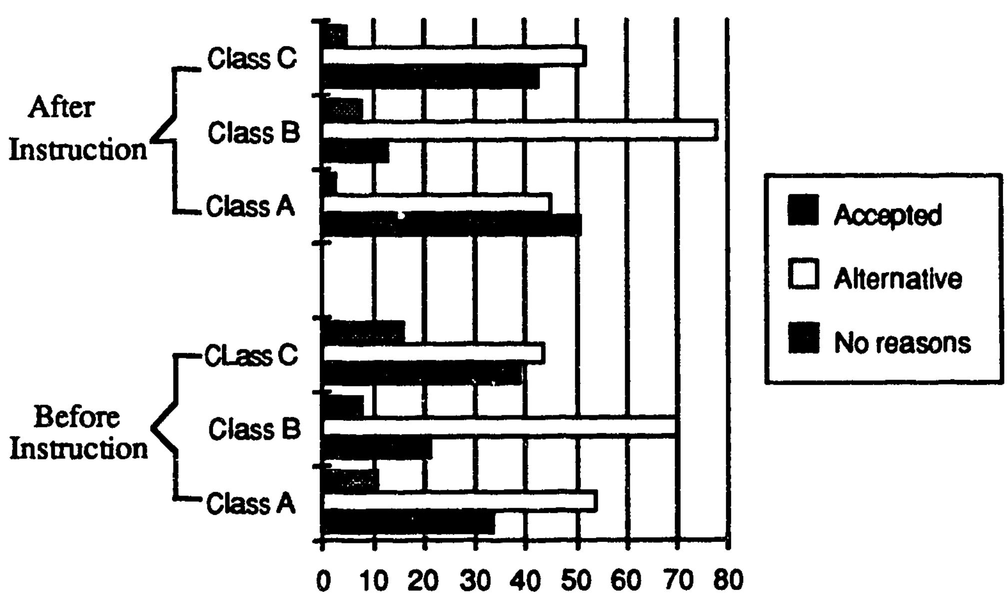
Nam: I can't answer right now considering evolution, but for this topic, I only know that there won't be any change.

Questions # 3.1 and # 3.2 were also adapted from the work of Kargbo *et al.* (1980). The students were presented with a picture of a black mouse and a white mouse, along with a picture of six baby mice in outline with no color indicated. Then they were asked to predict the colors of the offspring. (Question # 3.1 If a white male mouse and a black female mouse have six offspring, what colors would the offspring be? Why?) The purpose of this question was to determine students' viewpoints of probability in inheritance.

Figure 11 presents a summary of students' prediction to Question # 3.1 The accepted responses were:

1. any combination of black and white because one color is dominant to another, or
2. all black/white if one parent was homozygous dominant, or
3. unpredictable because there was not enough information about the parents' genotypes, or
4. depends on the chance of gene recombination.

Figure 11. The percentage of students' responses to Question # 3.1 before and after instruction.



Before any instruction, 34.29% of students in Class A, 21.62% in Class B, and 39.53% in Class C exhibited consideration of accepted genetic principles for their prediction although some of them predicted the ratio of 3:1 phenotypic outcome as related to the pea experiment of Mendel.

More than half of the students in each class (65.72% in Class A, 78.38% in Class B, and 60.47% in Class C) held alternative conceptions or had no ideas about the question. Their explanations varied from everyday experience, parenthood, and alternative genetic principle interpretation. For example, two students thought that the baby-mice would be black rather than white because a human couple of dark and white skin usually produced dark-skinned children. Eight students predicted that there would be more white offspring because the male parent often had dominant features. Moreover, twenty-one students from all classes pointed out that the offspring would be all black or white because the first filial generation (F_1) must be all dominant.

At the post-test, the question was modified by giving a phenotype of the offspring, then asking the students to predict the possibilities of the three male-mice being the father. (A student placed a white female guinea pig in a cage with 3 male guinea pigs, one white and two black. Later the female gave birth to a white offspring. Which of the males could be the father of the offspring, if black color is dominant to white? Why?)

The expected answer was either of the three male mice because the black male could be heterozygous. Only students from Class A (51.43%) expressed dramatic improvement of their understanding after instruction. Almost the same percentage of students in Class C responded with the accepted interpretations. Worse, the percentage of students in Class B reduced to 13.51%.

The majority of students (45.71% in Class A, 78.38% in Class B, and 52.38% in Class C) suggested alternative conceptions. More than one-fourth of each class believed that only the white male could be the father of the white offspring because white is recessive. They seemed to be unaware that the black male could be either homozygous or heterozygous. The other alternative interpretations included: the first filial generation (F_1) offspring with recessive features would come from the parents who were both recessive, and the black male mouse had more possibility of producing black offspring, therefore the white male mouse was more likely to be the father.

The following extracts reveal the reasoning that the students used in arriving at their answers. In the first interview which occurred before the unit instruction, Dam, from Class A, predicted that the baby mice would be black, white, and a mix of black and white. He stated that the number of each color could not be specified because:

> It depends on combinations of chromosomes. If the baby mouse received both chromosomes from its father, it would be white. If both (chromosomes) were from the mother, it would be black. But the combination of the mother's and the father's made the mixing of black and white resulted in piebald.

He supported his position with:

> The puppy of my neighbor is piebald. Its mother is black. I don't know the father, but when I saw the puppy, I guessed the father would be white.

Thida, also from Class A, predicted that there would be four black and two white baby mice.

> I think the white mouse is rare, especially if white is resulted from the abnormality of pigment cells, it would be more rare. The black color of the female mouse could be found everywhere. In mating, black color might be more powerful to white color. It masks white color of the male mouse.

When asked why the ratio of black and white was 4:2, Thida explained that:

> I used to learn when I was in the primary school. Mendel said that the ratio of dominant to recessive was 3:1...I cannot remember exactly...it was a long time ago.

She also emphasized that:

> The abnormality of pigment cells could not be a dominant feature because it is an abnormality.

Another interesting suggestion was given by Chana from Class B:

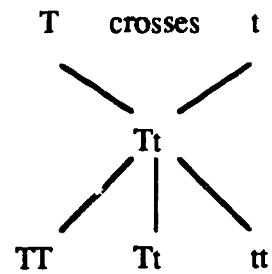
> The baby mice would be black and white...I cannot tell how many of each...but there would be more black than white. The baby develops in the mother's womb...therefore the baby would receive more features. Someone says that when the mother is pregnant, what she behaves, the baby would behave after. I used to watch a TV show, the interviewing with a movie star. She said that she was the only one in

her family that looked like the Westerners although both of her parents were Thai but her mother liked to look at the picture of a white baby.

An example of confusion surrounding the ideas of gene segregation and recombination was given by Nam, from Class C. She expected four white and two black baby mice and diagrammed her explanation as follows:

T = the male gene

t = the female gene



Resulted genes

white : black
2 : 1

The following is a portion of an interview with Nam about her diagram.

Interviewer: Why did you put the T for the male gene and the t for the female gene?

Nam: Well, I put gene T for the white phenotype and I understand that the dominant features usually come from the father.

Interviewer: Whatever color the father is?

Nam: Yes.

Interviewer: Why do the dominant features usually come from the father?

Nam: I had read from the book, the students' guide for diploma exam. It said that if the symbols are like this (Tt), it should be concluded that it (T) must be a color of the male.

Interviewer: Either black or white, the color from the male must always be dominant?

Nam: (Hesitate) It might not always be but I don't know.

Interviewer: O.K. and can you explain more about the diagram?

Nam: Well, gene T from the father combines with gene t from the mother resulted in Tt. Then take a pair of symbols which are the same, similar to making a diagram of mathematical probability. Take all possible combinations of that pair of genes.

Interviewer: So what is this Tt (the second line of the diagram)?

Nam: The mice resulted from a cross.

Interviewer: And what are these (TT, Tt, tt)?

Nam: (Pause) I did wrong at that time. It was wrong. I mean it ... (pause) ... I might take the offspring and crossed them again. That's why I did wrong.

Interviewer: So what do you think to be correct?

Nam: I can't remember. What I had read, we must make a grid, consider a pair of genes, match each pair of them, then consider the ratio. It came out as a ratio of 2:1-two white mice to every black mouse. Therefore I put four white and two black mice.

From these interview transcripts, it is clear that these students did have some prior knowledge of Mendelian genetics that was likely too vague to relate to the knowledge of meiosis and fertilization. Some students tended to construct ways of thinking based on everyday experiences.

After the instruction, among the students who thought that only the white male could be the father of the white offspring, most of them were unaware of the possibility of the black male being heterozygous. Phol, from Class A, was an example of this case.

Phol: White is recessive, black is dominant, the dominant trait will mask the recessive trait.

Interviewer: Is it possible that the black male mouse could be the father?

Phol: The father must be heterozygous. The heterozygous black mouse may produce the white offspring. I forgot this possibility.

In contrast, Phong from Class B, presented an alternative conception which arose from the instruction:

Phong: The white male is the father because they have the same characteristics.

Interviewer: Can you explain through genetic principles?

Phong: Recessive trait and recessive trait produce recessive offspring.

Interviewer: Can a black male be the father?

Phong: Well, it is possible. There are some white baby mice. This resulted from the incomplete dominant, therefore, the offspring came out in white.

As well, Kam, from Class C, demonstrated another alternative conception:

Kam: The black male mouse could be the father because there is one white offspring in the F_2 generation. This resulted in a 3:1 ratio.

Interviewer: How do you know this is the F_2 generation?

Kam: Well, Mendel's principle indicated that F_2 which resulted from a cross between the F_1 would produce offspring consisting of three dominant and one recessive traits. The offspring of the F_1 generation must be all dominant trait if the mother has the recessive trait.

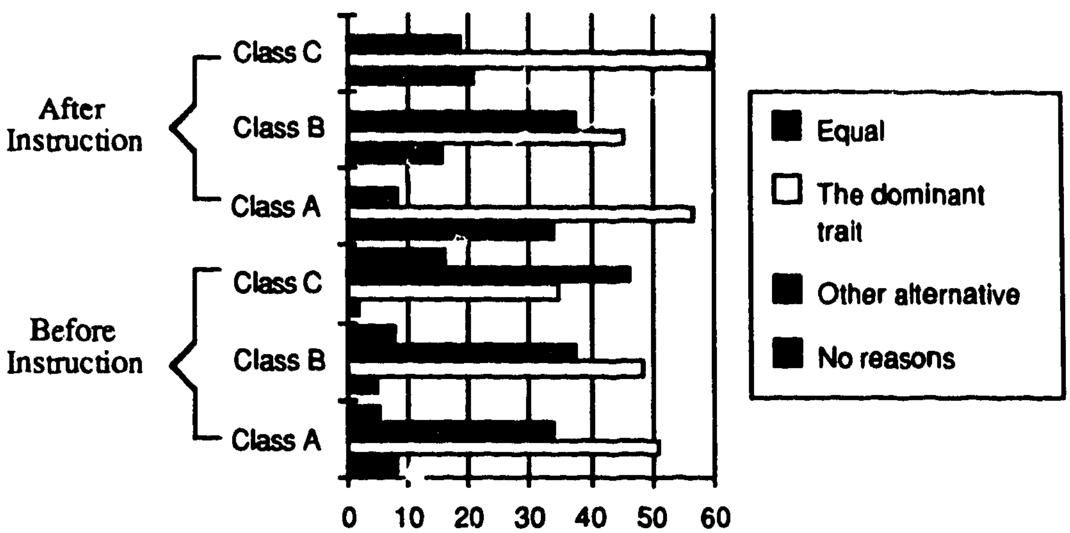
Question # 3.2 was administered to probe for the understanding of the equality of genetic contribution by each parent in sexual reproduction. (Which one of the parent mice do you think will have greater influence on the characteristics of the offspring? Why?)

Before any instruction, only 8.57% of students in Class A, 5.41% in Class B, and 2.33% in Class C stated that both parents had equal influence because each passed on half of the chromosomes to each offspring as shown in Figure 12.

About half of the students in Class A and Class B (51.43% and 48.65% respectively) and one-third of Class C (34.89%) had the notion of "dominance" as synonymous with phenotypic characteristics. Consequently, they suggested that the parent with dominant color would have greater influence. Interestingly, some other students conceived the inequality of the parents' contribution, for example, 15 out of

115 students explained that the mother might have greater influence because she acted as an incubator and a nourisher for the embryo, whereas 16 students believed in the father for the reason of his strength and that sperm determined the offspring's characteristics.

Figure 12. The percentage of students' responses to Question # 3.2 before and after instruction.



After the completion of instruction, there was a slight increase in the percentage of students who conceived the accepted response (34.29% in Class A, 16.22% in Class B, and 21.43% in Class C). Slightly more students in Class A and Class C (57.14% and 59.52% respectively) and slightly less students in Class B (49.54%) retained the belief of dominance synonymous with a strong personality. 8.57% of Class A, 37.84% of Class B, and 19.05% of Class C held other alternative conceptions about the inequality of the parental gene contribution.

The following examples are short segments of interviews aimed to probing students' underlying conceptions about parental gene contribution.

Dam (Class A) thought that the mother would contribute more because:

> She is the one who is pregnant. The baby was inside her womb, so it was closer.

Khom (Class A) believed that:

> The mother, because she is black. In arts, black stands out from white. When white mixes with other colors, it could only make those colors dilute. But if we mix black with other colors, the colors will change. As well as in the inheritance, the transmitter who is black would have greater influence than the white.

Chana (Class B) had the same idea:

> The baby develops in the mother's womb, therefore, the baby would receive more features. Someone says that when the mother is pregnant, what she behaves, the baby would behave after.

In contrast, Wichit (Class B), believed that:

> The father will contribute more. An embryo would originally develop when a sperm mated. Tremendous sperms are produced in meiosis but only one sperm can successfully mate, therefore, I think the offspring would get more features from the father.

Porn (Class C) expressed another interpretation:

> The father will contribute more because male has more chromosomes than female. Male has the Y-chromosome. The genes that cause hereditary disease, when located on the Y chromosome, even when only one gene is presented, can develop the disease. I think the father must have greater influence.

Nut (Class C) pointed out an interesting explanation:

> It depends on the father. The stronger one has more hereditary indicators. If the father is weak...he will have less hereditary indicators, then the mother can express more, but if the father is strong...the mother will take part less.

Students' explanations to this question vary from everyday experiences to bits and pieces of knowledge about reproduction and inheritance.

In the interviews after the completion of unit instruction, out of six students from each class, three from Class A, three from Class B, and one from Class C demonstrated an understanding of the equality of the parents' contribution. Two students from each class persisted in their beliefs that the parent who had the dominant trait would contribute more whereas one student from Class A, one from Class B, and three from Class C provided alternative explanations as shown in the following:

Dam (Class A): The mother contributes more. The baby was in her womb. All of our siblings except one are more like our Mom.

Phong (Class B): In general they (the parents) have equal influence. We could see that some offspring look more like the father but some may be more like the mother. The offspring get something from the mother and the other things from the father.

Porn (Class C): The father has greater influence because he usually has dominant traits. Most offspring inherit dominant traits from the father.

Questions # 4.1 and # 4.2 were given to probe students' viewpoints about the likeness and variation within the same family. Students were asked to explain why siblings usually look alike. (Question # 4.1 Why are children at the same family frequently look like one another?, # 4.2 Why are children at the same family not identical?)

Table 3 summarizes students' responses to Question # 4.1. Before any instruction almost all of the students have some ideas about why there are likenesses between siblings. 42.86% of students in Class A, 45.95% of students in Class B, and 58.14% in Class C explained that the siblings inherited genes or chromosomes that determined the similar appearance. 8.57% in Class A, 32.43% in Class B, and 13.95% in Class C referred to the traits the siblings inherited from the same parents. 42.86% in Class A, 21.62% in Class B, and 25.58% in Class C mentioned the parental gametes as sources of likeness. However, one student in Class A believed in the environment where the siblings grew up together, and another student in Class C considered the amount of traits that passed on to the offspring.

After the instruction, 57.14% of students in Class A, 32.43% of Class B, and 61.90% in Class C mentioned about genes or chromosomes. Some of them even realized that there were limited patterns of combinations of hereditary packets in a family which made them more similar in appearance than to children from other families. 34.29% of students in Class A, 45.95% of Class B, and 21.43% of Class C were consistent in their shallow explanations about gametes and traits from the same sources. Two students from each class turned to other alternative conceptions. For example, one student viewed that the first filial generation (F_1) should have the same phenotypes, two other students mentioned about the dominant genes the children inherited from their parents, and the others believed that equal distribution of genes from their parents resulted in likeness between siblings. It was interesting that more students got confused which led them not to respond to the question (totally 12 out of 114).

Table 3. The percentage of students' responses to Question # 4.1 before and after instruction.

Type of Responses	Percentage of Students					
	Before Instruction			After Instruction		
	Class A (n=35)	Class B (n=37)	Class C (n=43)	Class A (n=35)	Class B (n=37)	Class C (n=42)
*Responses mentioned about genes/ chromosomes.	42.86 (n=15)	45.95 (n=17)	58.14 (n=25)	57.14 (n=20)	32.43 (n=12)	61.90 (n=26)
**Responses mentioned about traits.	8.57 (n=3)	32.43 (n=12)	13.95 (n=6)	22.86 (n=8)	43.24 (n=16)	16.67 (n=7)
**Responses mentioned about parental gametes.	42.86 (n=15)	21.62 (n=8)	25.58 (n=11)	11.43 (n=4)	2.70 (n=1)	4.76 (n=2)
Alternative reasons.	2.86 (n=1)	0.00 (n=0)	2.33 (n=1)	5.71 (n=2)	5.41 (n=2)	4.76 (n=2)
Not clear reasons.	2.86 (n=1)	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)
No answers.	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	2.86 (n=1)	16.22 (n=6)	11.90 (n=5)

* = accepted response
** = accepted response as partial understanding

Question # 4.2 required the students to explain why two children, except identical twins, could never be exactly alike. As shown in table 4, before any instruction, less than a third of students in each class (31.43% of students in Class A, 24.32% in Class B, and 25.58% in Class C) mentioned the inheritance of different chromosomes/genes from the parents although they did not give more details. While 20% of Class A, 29.73% of Class B, and 4.65% of Class C just simply stated that each gamete was somewhat different from each other and 5.71% of Class A, 21.62% of

Class B, and 23.25% of Class C suggested that children inherited different characteristics each time. Many students (42.86% in Class A, 24.32% in Class B, and 46.51% in Class C) held alternative interpretations including amounts of genes/ chromosomes or characteristics they inherited, different genes/chromosomes orders, and the influence of time and environment.

Table 4. The percentage of students' responses to Question # 4.2 before and after instruction.

Type of Responses	Percentage of Students					
	Before Instruction			After Instruction		
	Class A (n=35)	Class B (n=37)	Class C (n=43)	Class A (n=35)	Class B (n=37)	Class C (n=42)
*Each gamete has different sets of Chromosomes/genes.	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	57.14 (n=20)	2.70 (n=1)	26.19 (n=11)
**They inherit different chromosomes/genes.	31.43 (n=11)	24.32 (n=9)	25.58 (n=11)	2 86 (n=1)	13.51 (n=5)	16.67 (n=7)
**Each gamete is somewhat different.	20.00 (n=7)	29.73 (n=11)	4.65 (n=2)	8.57 (n=3)	13.51 (n=5)	2.38 (n=1)
**Each time they inherit different characteristics.	5.71 (n=2)	21.62 (n=8)	23.25 (n=10)	17.14 (n=6)	27.03 (n=10)	11.90 (n=5)
Alternative reasons	42.86 (n=15)	24.32 (n=9)	46.51 (n=20)	8.57 (n=3)	27.03 (n=10)	30.95 (n=13)
No answers	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	5.71 (n=2)	16.22 (n=6)	11.90 (n=5)

* = accepted response
** = accepted response as partial understanding

The post-test results indicated that 57.14% of Class A, 2.70% of Class B, and 26.19% of Class C demonstrated more precise understandings why siblings had different genetic entity. They mentioned different combinations of hereditary packets produced by the same couple and the differentiation that resulted from the crossing-over of the chromosomes during meiosis. However, some students still had no idea of what made the sets of genes different (2.86% in Class A, 13.51% in Class B, and 16.67% in Class C).

8.57% of Class A, 13.51% of Class B, and 2.38% of Class C were consistent in their understandings at the superficial level that it was because the children were born from different eggs and sperms.

There were some alternative conceptions presented after instruction. 8.57% of Class A, 27.03% of Class B, and 30.95% of Class C held alternative conceptions including unequal amounts of genes/chromosomes or features, differences of parents' chromosomes, and the different portions of genotypes they got.

Examples of students' prior conceptions about the similarities and differences between siblings are provided by the following:

Dear from Class A explained that:

> The siblings have the same parents. The genes and characteristics transmitted should be identical. The features inherited from our parents would differ from the genes and characteristics which our friends' parents transmitted to their children.

However, Dear was confused about the differences:

> I understand that we take the same amount of chromosomes from each parent. The genes we get should also be equal but it contradicts. I mean if we get the same contribution, why do we still look different? I think the genes contributed from the father and the mother are not equal. I don't know why. Like me, I look more like my father, I should take more from my father, but my sister looks more like my mother, she might take more from her. We look similar because we take from the same parents but unequal amounts of genes were contributed to make us look different.

Chana from Class B suggested another viewpoint:

> The siblings were born from the sex cells of the same parents and those sex cells incidentally have the same features.

In responding to the question why the siblings look different, she explained that:

> The sex cells have something strange. It might be because of the hormones or something like that. This results in some different characteristics.

Another interesting interpretation came from Karn (Class C) in the following interview excerpts.

> Karn: They are kin. The first child takes chromosomes from the parents. As well, the second child takes the same genes and chromosomes as the first did.
>
> Interviewer: So why are they not exactly alike if you think they have the same genes and chromosomes?
>
> Karn: (pause) I cannot answer right now...(pause)...but it might have resulted from a crossing over.
>
> Interviewer: What do you mean by a crossing over?
>
> Karn: I got this word from the students guidebook for diploma exam. I vaguely remembered that it said that such genetic variations were caused by crossing-over, the skip-over mating or something like that. They mated across the steps. The children born with different looks might have resulted from these factors, but I am not confident of what crossing over is.

In the final interviews, more students could provide more definite explanations. Five out of six students from Class A referred to the possibilities of the chromosome segregation and recombination although some of them still used a general idea like "dominant and recessive traits." For example, Khom explained why the siblings look alike like this:

> They were born from sperms and eggs which come from the same parents. Therefore the genes that contributed to each sex cell would be one of the pair that exist for each trait. Thus the chromosomes and genes which were transmitted are alike.

As for the variation, he suggested that:

> During the meiosis, each spermatocyte or oocyte could produce four daughter cells. Each cell has different combinations of chromosomes. That's why the siblings are not identical.

In contrast, Dam retained his simplistic and alternative conceptions:

(They are alike) because they come from the same parents. They inherited the same traits.

(They are different) because the genes they inherited are not the same. The genes which bound together into a sex cell do not control the same traits. Some genes may control the height but some controls the hair..things like that. Some offspring may get the mother's appearance but the others do not.

When asked how many genes control a particular trait, Dam responded that:

One gene for one trait. Several traits come to match in pairs. So, the siblings are not exactly alike.

Similarly, Chana, one of the two students from Class B who presented alternative conceptions described her idea in the following excerpts from the interview.

Chana: They are alike because they inherit the same traits. There is a possibility that the sex cells are alike.

Interviewer: If the sex cells are alike, why does each sibling have his or her own identity?

Chana: The sex cells may be different. They control different traits like..this cell gets the appearance, the other gets the height.

Interviewer: Don't these traits come into every sex cell?

Chana: (pause) Well, there might be some error.

Karn, from Class C, who thought that the variations resulted from "crossing over" in her first interview, continued her interpretation:

Karn: During the formation of sex cells. Oh, no, when the sperm and the egg fuse together, the chromosomes which match may exchange their segments and result in the difference between each phenomenon. Some segment gets the dominant traits. Some segment includes that point and this point. This causes the siblings to be different but they also inherit dominant traits of their parents.

Interviewer: Do you mean that these phenomena occur during the formation of the zygote?

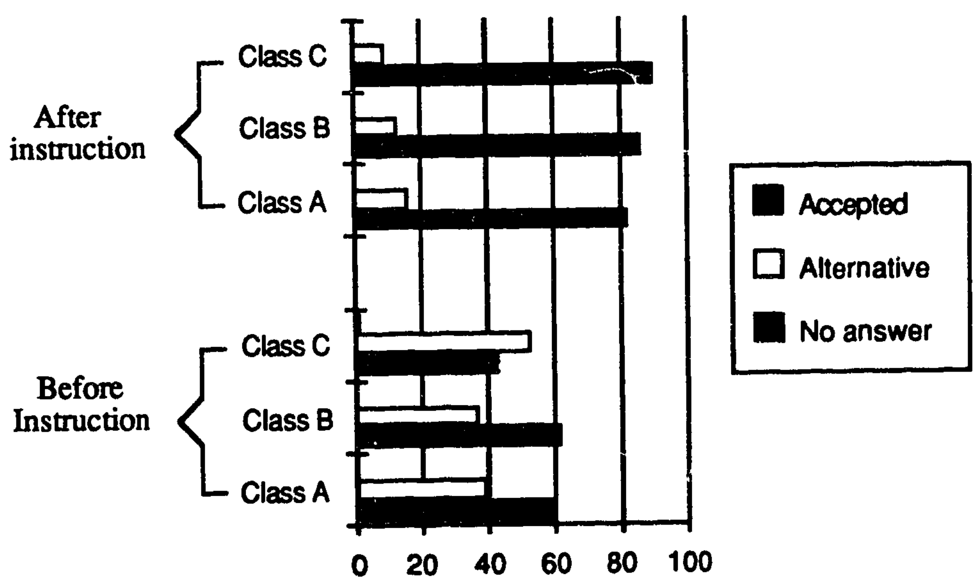
Karn: (pause) No, but I don't know either what it is.

Questions # 5.1, # 5.2, and # 5.3 attempted to assess students' prior knowledge about the genes. They were presented with the word "GENES" located in a question mark, then they were asked, "What are genes ?" (Question # 5.1).

The acceptable response was that genes are specific units (of the DNA molecule) which determine hereditary characteristics of living things.

Figure 13 summarizes students' responses to Question # 5.1 before and after instruction. Before any instruction, about half of the students in each class (60.00% in Class A, 62.16% in Class B, and 44.17% in Class C) presented a basic correct definition of the genes, others held alternative conceptions. Four students (9.30%) in Class C understood that a gene is made up of DNA, they thought of a gene as a storage of hereditary characteristics. Other students believed that a gene was a gamete, a cell, one type of chromosome, or even a trait itself. Only one student (2.33%) in Class C did not give any response to the question.

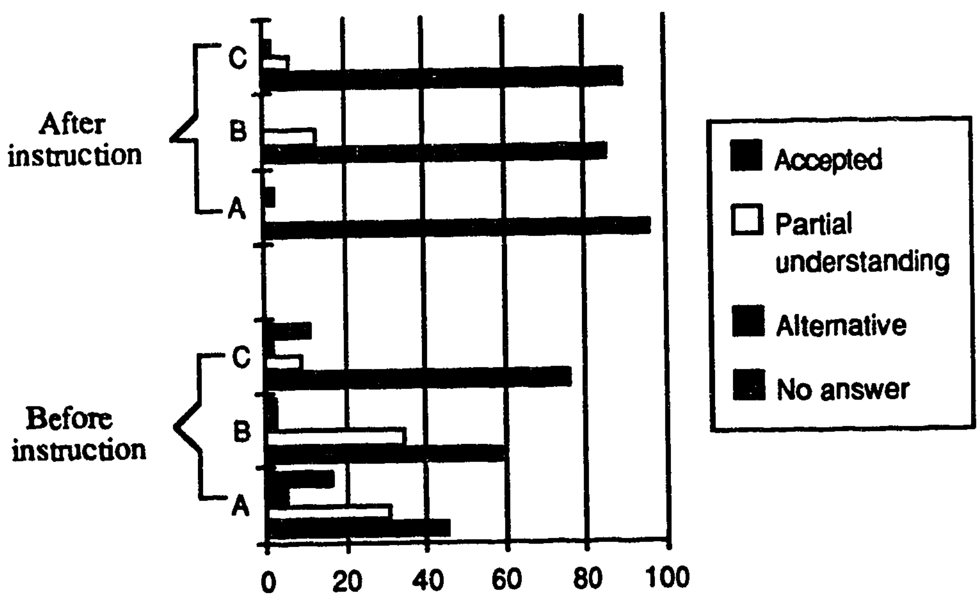
Figure 13. The percentage of students' responses to Question # 5.1 before and after instruction.



After instruction, the number of students who offered correct answers increased to 82.86% in Class A, 86.49% in Class B, and 90.48% in Class C. However, none of the students in this group demonstrated a deeper understanding than what was given in the pre-test. 17.14% in Class A, 13.51% in Class B, and 9.52% in Class C retained their alternative conceptions. Some students retained their beliefs of a gene being synonymous with a gamete, a cell, or a trait itself while other students switched to other alternative conceptions. They thought the gene was a protein compound or an organ located in a cell.

Question # 5.2 probed students' knowledge about the location of the genes (Where are genes located?). Before the formal instruction, 45.71% of students in class A and more than half of the students in Class B and Class C (59.46% and 76.74%, respectively) believed that the genes are located on the chromosomes as presented in Figure 14. 31.43% in Class A, 35.14% in Class B, and 9.30% in Class C responded that the genes were in a nucleus, a gamete, a cell, gametal chromosomes, a zygote, or our body. One student in Class B indicated that the genes had no specific location, they were present only during reproduction. Other students (Class A and Class C) believed that the parental genes were in the reproductive system whereas the offspring's genes were in the growing part of the body. Another student responded that genes were located on a chromosome of a chromatid.

Figure 14. The percentage of students' responses to Question # 5.2 before and after instruction.



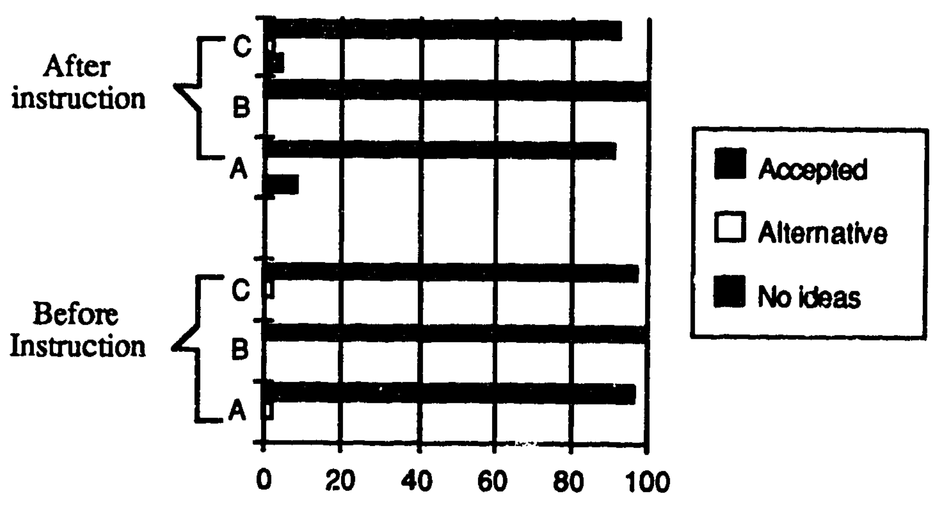
After instruction, most students of each class (97.14% of Class A, 86.49% of Class B, and 90.48% of Class C) demonstrated their understandings of where the genes are located. 13.51% of Class B and 7.14% of Class C retained their conceptions that the genes were in a gamete, gametal chromosomes, or every part of our body.

2.86% of Class A and 2.38% of Class C expressed another alternative conception; that genes were located in pairs on a single chromosome.

When asked about the functions of genes in genetic transmission (Question # 5.3 How does a gene function in the transmission of traits?), before instruction, none of the students demonstrated correct understanding (see Figure 15).

Almost all students (97.14% of Class A, 100.00% of Class B, and 97.67% of Class C) had no idea of how the genes functioned. They just stated that the genes "instruct," "control," "specify," or "pass on" traits to the offspring and some students noted that they had no ideas at all. One student from Class A (2.86%) thought that the parental genes would exchange by crossing over of chromosomes, whereas another student from Class C (2.33%) explained that the genes control the body growth through chemical codes.

Figure 15. The percentage of students' responses to Question # 5.3 before and after instruction.



After instruction, there was no progress in students' understandings. Only 8.57% of Class A, and 4.76% of Class C provided more details such that each pair of genes "code" for specific characteristics. Whereas 91.43% of Class A, 100.00% of Class B, and 92.86% of Class C were consistent in their shallow explanation that genes passed on traits to the offspring. Worse, one student (2.38%) from Class C demonstrated her confusion related to a genotype and a phenotype by specifying that genes functioned by having a genotype as characteristics and a phenotype as an indicator of characteristics to be expressed.

The following excerpts from the first interviews serve as examples of students' ideas about genes.

Dear (Class A) had partial understanding of what genes were but had no idea about their location and function.

Interviewer: Can you tell me what genes are?

Dear: They are something that transfer parental characteristics to the offspring.

Interviewer: Can you explain further?

Dear: I don't think so.

Interviewer: Do you have any idea about where they are?

Dear: Well, they must be in our body but I don't know exactly what specific place they are. They (genes) will transfer when they (parents) have children.

Nut (Class C) demonstrated his confusion about hereditary characteristic.

Nut: Genes are something that transfer dominant characteristics to the offspring.

Interviewer: Only dominant characteristics?

Nut: Well, there are other characteristics too, like stature, appearance.

Interviewer: What are the differences between those groups of characteristics?

Nut: (silent)

Interviewer: Are the fur coat colors of the mice in the previous question, both black and white, dominant characteristics?

Nut: White is dominant but black is recessive.

Interviewer: Therefore, do the genes transfer only the dominant color-the white?

Nut: They transfer recessiveness too, but only some.

Interviewer: Can you tell me where the genes are?

Nut: On the chromosomes.

Interviewer: How do you know?

Nut: My friend told me.

Interviewer: Do you also know how the genes function?

Nut: I don't know at all.

Only Chana (Class B) provided more information about gene function.

Chana: Genes are sections which will express dominant characteristics of living things.

Interviewer: Do they express only dominant characteristics?

Chana: Well, they express both dominant and recessive characteristics but tend to be more dominant.

Interviewer: What is the relationship between the genes and the expressed characteristics?

Chana: They are the same thing.

Interviewer: Do you know where the genes are?

Chana: On the chromosomes.

Interviewer: How do you know?

Chana: My teacher taught me when I was in grade six.

Interviewer: Do you know more about this?

Chana: It's a long time ago. I can't remember.

Interviewer: Do you have any ideas about how the genes function?

Chana: They transfer through the sex cells. They might be like hormones, help stimulate. They are alike.

Interviewer: Do you mean the genes and the hormones are alike?

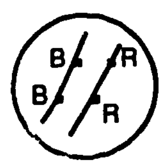
Chana: Not really, but I am trying to compare that they are similar in function. For example, if there are more masculine hormones, you will have more masculine characteristics. They are similar. The genes are like that-what dominant characteristics are, the expressions are too.

After the instruction, most students could not provide any more details about what genes were or how they functioned. Furthermore, some demonstrated other alternative conceptions as they tried to give more information. Notice the following:

Thida from Class A, who was able to draw a commonly accepted model of genes and chromosomes, understood that:

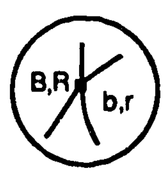
> Genes are units that control the traits which are transmitted from ancestors to descendants. They are a protein substance.

Also, Krisda from Class A, revealed his alternative conceptions when he was asked to draw a model. His model was like this:



He explained that "each gene locates in a pair on chromosomes."

Another interesting interpretation came from Chana, from Class B. Her model was like this:



She described that:

> Before a cell undergoes a meiotic division, every gene will be bound together at a centromere. Until after the completion of cell division, they will line up on a chromosome. Because the alleles locate at the same loci on a pair of homologous chromosomes, when they (chromosomes) recombine after fertilization, the genes will be bound together again at the centromere."

In contrast, Porn from Class C, could not provide a model to express her thought but she explained that "genes are like rice grains packed in a bag-a chromosome."

Session II Tasks

Questions # 6 to # 8. Questions # 6 to # 8 were given in the second session of written tasks which was held before the instruction of monohybrid cross. These questions were developed to probe students' interpretations about some general public notions related to genetics and some specific genetic concepts about the monohybrid cross.

Questions # 6.1 and # 6.2 were adapted from questions developed by Engel Clough and Wood-Robinson (1985). They were added to determine students' views about the possible inheritance of human skills.

Question # 6.1 A couple had trained hard to become good runners (though they were not particularly proficient naturally), would their children be automatically good runners? Why? The accepted response for the question was that the children could not be automatically fast runners because developed skills have no effect on one's genetic make-up.

Table 5 illustrates the comparative results of students' responses to Question # 6.1. In the first round of this question, 31.43% of students in Class A, 17.14% of Class B, and 28.21% of Class C, demonstrated understandings of the substantial role of genetic factors in human skills. Whereas 40.00% of Class A and Class B, and 33.34% of Class C just simply believed that it was because their parents were not born as good runners or there was no trait for fast running ability in the family. 22.86% of Class A, 25.71% of Class B, and 30.77% of Class C believed that athletic skills were not affected by genetic factors at all.

2.86% of students in Class A and 8.57% in Class B explained their alternative interpretation that the children would not be automatically fast runners because fast running ability was a recessive genetic factor or it was too soon for any change to be demonstrated.

It was not a surprise to have 2.86% of students in Class A, 8.57% in Class B, and 7.69% in Class C who believed that this skill would be transmitted immediately to the next generation.

Table 5. The percentage of students' responses to Question # 6.1 during and after instruction.

Type of Responses	Percentage of Students					
	During Instruction			After Instruction		
Answer & Reason	Class A (n=35)	Class B (n=35)	Class C (n=39)	Class A (n=35)	Class B (n=37)	Class C (n=42)
No Change:						
*No genetic/gametic change.	31.43 (n=11)	17.14 (n=6)	28.21 (n=11)	54.29 (n=19)	24.32 (n=9)	33.33 (n=14)
**No trait for fast running ability in this family.	11.43 (n=4)	17.14 (n=6)	10.26 (n=4)	14.29 (n=5)	27.03 (n=10)	14.29 (n=6)
**Parents were not born as fast runners.	28.57 (n=10)	22.86 (n=8)	23.08 (n=9)	11.43 (n=4)	13.51 (n=5)	14.29 (n=6)
Could be acquired only through practice.	22.86 (n=8)	25.71 (n=9)	30.77 (n=12)	14.29 (n=5)	18.92 (n=7)	33.33 (n=14)
Other alternative reasons including no explanations.	2.86 (n=1)	8.57 (n=3)	0.00 (n=0)	2.86 (n=1)	10.81 (n=4)	0.00 (n=0)
Automatically good runner:						
Various alternative reasons.	2.86 (n=1)	8.57 (n=3)	7.69 (n=3)	2.86 (n=1)	2.70 (n=1)	4.76 (n=2)
No reasons.	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	2.70 (n=1)	0.00 (n=0)

* = accepted response
** = accepted response as partial understanding

The post-test results indicated that the percentage of students who correctly answered this question through appropriate genetic principles rose to 54.29% of the students in Class A, 24.32% in Class B, and 33.33% in Class C whereas 14.29% of Class A, 27.03% of Class B, and 14.29% of Class C still believed that there was no trait for fast running ability in the family. As well, 11.43% of Class A, 13.51% of Class B, and 14.29% of Class C retained their reason that the parents were not born automatically fast runners. The students who held alternative views dropped to 20.01% in Class A, 35.13% in Class B, and 38.09% in Class C.

Question # 6.2 was given for the purpose of determining the effect of time on the possibility of inheritance of developed skills. (If the children of this family practiced hard over several generations would you get automatically fast runners in about 200 years? Why?)

After two periods of instruction of the unit, 31.43% of students in Class A, 34.29% in Class B, and 20.51% in Class C, demonstrated their understanding that environmentally produced characteristics did not effect any genetic change (see Table 6). In this group, one student (2.86%) from Class B added that running skill depended upon the body competency. 17.14% of students in Class A and Class B and 15.38 % in class C simply believed that the children would never be automatically good runners because their parents were not born as fast runners or there was no trait for fast running ability in this family. 20.00% of Class A, 11.43% of Class B, and 25.64% of Class C believed that genetic factors had no effect on this skill. More than one fourth of each class (28.57% of Class A, 31.43% of Class B and 25.64% of Class C) thought that the developed skill could be passed on to the offspring after a period of time.

Some students indicated that it was unpredictable because it might not be long enough for any change and the others suggested that it depended on what genes the children got (2.86% in Class A, 5.71% in Class B, and 10.26% in Class C). There was one student (2.56%) from Class A who stated that he had no idea.

At the post-test, the percentage of students correctly answered rose up to 42.86% in Class A and 30.95% in Class C, but it dropped to 18.92% in Class B. Moreover some students in this group indicated more deeply that although the genetic make-up might not change, the phenotypes could often be modified by environmental factors. Therefore, in this case, the children could be good runners if they continued practicing.

Table 6. The percentage of students' responses to Question # 6.2 during and after instruction.

Type of Responses	Percentage of Students					
	During Instruction			After Instruction		
Answer & Reason	Class A (n=35)	Class B (n=35)	Class C (n=39)	Class A (n=35)	Class B (n=37)	Class C (n=42)
No Change:						
*No genetic/gametic change.	31.43 (n=11)	34.29 (n=12)	20.51 (n=8)	42.86 (n=15)	18.92 (n=7)	30.95 (n=13)
**No trait for fast running ability in this family.	8.57 (n=3)	11.43 (n=4)	15.38 (n=6)	14.29 (n=5)	18.92 (n=7)	14.29 (n=6)
**Parents were not born as fast runners.	8.57 (n=3)	5.71 (n=2)	0.00 (n=0)	0.00 (n=0)	5.41 (n=2)	2.38 (n=1)
Could be acquired only through practice.	20.00 (n=7)	11.43 (n=4)	25.64 (n=10)	0.00 (n=0)	18.92 (n=7)	35.71 (n=15)
Other alternative reasons including no explanations.	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	2.86 (n=1)	10.81 (n=4)	0.00 (n=0)
Automatically good runner:						
Various reasons.	28.57 (n=10)	31.43 (n=11)	25.64 (n=10)	40.00 (n=14)	21.62 (n=8)	14.29 (n=6)
Unpredictable: various reasons.	2.86 (n=1)	5.71 (n=2)	10.26 (n=4)	0.00 (n=0)	2.70 (n=1)	0.00 (n=0)
Don't know.	0.00 (n=0)	0.00 (n=0)	2.56 (n=1)	0.00 (n=0)	2.70 (n=1)	2.38 (n=1)

* = accepted response
** = accepted response as partial understanding

The number of students who held alternative interpretations dropped to 42.86% in Class A and 52.38% in Class C, but it rose to 56.75% in Class B. The most common alternative conception was that although the children would or would not be born with automatically good skill, their body structure would improve dramatically as a result of being the descendants of athletes. There were a number of students (14.29% in Class A, 24.33% in Class B, and 16.67% in Class C) who held the common ideas that it was because the parents were not automatically fast runners or there was no trait of good runners.

When compared to responses to question # 6.1, the responses to Question # 6.2 indicated that, both before and following instruction, more students believed that although the phenotypic change might not be immediately passed on to the next generation, it might be transmitted later.

The following extracts during the final interviews reveal students' alternative reasoning about the transmission of developed skills.

Dam (Class A) believed that the developed skills could not be transmitted but the strength body structure which was resulted from athletic training might be passed on to the offspring as he suggested:

> The children could not be automatically fast runners because any skill must be acquired only through practice. If the children try hard in practice, they would be able to be a good runner. But they will inherit their parents' features of strong muscles.
>
> Two hundred years is a very long time, the children could be automatically fast runners. There has been a continuous development of the body structure system. The far future generations will be born with the full body system for being a fast runner.

When asked whether characteristics resulting from plastic surgery would be passed on to the offspring, Dam confidentially responded that:

> Plastic surgery is unnatural, but the muscles are in the body.

As well, Trakul from Class B, provided a similar idea:

> Running ability depends on practice. It is a specific skill of each individual. It can not pass on to others.

(In the next 200 years) Their (the offspring's) body conditions would be more appropriate for running. The strength would be transmitted to the offspring but running ability could not be.

In contrast, Porn (Class C), asserted that there would not be any change even after a long period of time but she still believed that genetic factors had no effect in human skills.

Running ability is more likely acquired through practice; there is no relation to hereditary characteristics.

(In the next 200 years) The genes still will not change. It is impossible for the children to be automatically fast runners.

When asked how evolution occurred, she remained quiet for a while, then responded that:

Well, how do they change? The genes must change but how, I don't know.

Question # 7 examined students' knowledge about the monohybrid cross. By specifying the dominant and recessive traits, students were asked to predict the genotypes of each possible gamete produced by a garden pea plant. (Question # 7.1 What are the genotypes of each possible gamete produced by a pea plant that is heterozygous green pod?)

Table 7 summarizes students' responses to Question # 7.1. Before the formal instruction, few students from each class (22.86% of Class A, 20.00% of Class B, and 2.56% of Class C) could provide the expected answer. Most students from Class A and Class B (65.71% and 80.00% respectively) and 12.82% from Class C answered the question with reference to a diploid cell instead. Some other students, 5.71% from Class A and 12.82% from Class C, provided phenotypic results whereas 5.71% of Class A and 71.79% of Class C did not respond to the question at all. One student from Class C who did not answer the question specified that she did not know the words "genotypes" and "heterozygous."

After instruction, the majority of students from Class A and Class B (65.71% and 86.11%, respectively), and 37.21% of Class C provided alternative conceptions that a gamete carried both alleles for a trait as in a diploid cell. As well, 27.91% of Class A and 5.56% of Class C provided phenotypic results. Unfortunately, 20.00% of students in Class A, 5.56% in Class B, and 11.63% in Class C misunderstood the genotypes of specimens given in the problem and some demonstrated misunderstanding in using symbols for the alleles involved in the problem. There were 5.71 % of Class A, 2.78% of Class B, and 20.93% of Class C who did not give any responses.

Table 7. The percentage of students' responses to Question # 7.1 before and after instruction.

Type of Responses	Percentage of Students					
	Before Instruction			After Instruction		
	Class A (n=35)	Class B (n=35)	Class C (n=39)	Class A (n=35)	Class B (n=36)	Class C (n=43)
*Correct understanding of monohybrid gamete types were given.	22.86 (n=8)	20.00 (n=7)	2.56 (n=1)	8.57 (n=3)	5.56 (n=2)	2.33 (n=1)
Genotypes of diploid cells were given.	65.71 (n=23)	80.00 (n=28)	12.82 (n=5)	65.71 (n=23)	86.11 (n=31)	37.21 (n=16)
Phenotypic results were given.	5.71 (n=2)	0.00 (n=0)	12.82 (n=5)	0.00 (n=0)	0.00 (n=0)	27.91 (n=12)
Other alternative conceptions.	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	20.00 (n=7)	5.56 (n=2)	11.63 (n=5)
No ideas.	5.71 (n=2)	0.00 (n=0)	71.79 (n=28)	5.71 (n=2)	2.78 (n=1)	20.93 (n=9)

* = accepted response

Question # 7.2 asked the students to predict the resulting genotypes of the offspring and to construct a diagram representing a cell, chromosomes, and genes involved in the problem to support their answers. (Give the resulting possible genotypes if a pea plant that is heterozygous is crossed to a pea plant that is homozygous green pod. Explain how you get the solution by making a diagram representing chromosomes and genes which are involved in the problem.)

As shown in Table 8, before the instruction of monohybrid lesson, 48.57% of students from Class A, 37.14% from Class B, and 5.13% from Class C predicted correct possible results and were able to assign functional symbols to the alleles involved in the problem. However, out of this group, only five students (14.29%) from Class A provided a cell diagram but assigned allelic symbols outside the diagram, whereas the others used a letter diagram to explain their results. Instead of giving the genotypic results, 17.14% of students in Class A provided phenotypic results. 28.57% of Class A, 62.86% of Class B, and 7.69% of Class C demonstrated alternative conceptions. Those conceptions included misunderstanding of parental genotypes, misunderstanding of the segregation of heterozygous genes to sex cells, using two different upper case letters to represent allele symbols for a trait, and using a rationale involving phenotypes to arrive at the answer.

Table 8. The percentage of students' responses to Question # 7.2 before and after instruction.

Type of Responses	Percentage of Students					
	Before Instruction			After Instruction		
	Class A (n=35)	Class B (n=35)	Class C (n=39)	Class A (n=35)	Class B (n=36)	Class C (n=43)
*Correct understanding of monohybrid cross were given.	48.57 (n=17)	37.14 (n=13)	5.13 (n=2)	42.86 (n=15)	38.89 (n=14)	16.28 (n=7)
Phenotypic results were given.	17.14 (n=6)	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	20.93 (n=9)
Other alternative conceptions.	28.57 (n=10)	62.86 (n=22)	7.69 (n=3)	51.43 (n=18)	55.56 (n=20)	32.56 (n=14)
No answers, no explanations.	5.71 (n=2)	0.00 (n=0)	87.18 (n=34)	5.71 (n=2)	5.56 (n=2)	30.23 (n=13)

* = accepted response

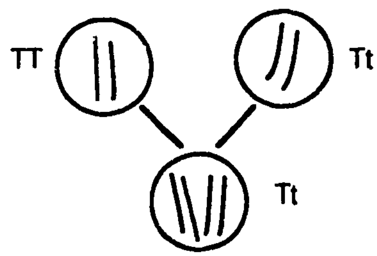
After the instruction, percentages of students giving the expected response decreased in Class A (42.86%) and slightly increased in Class B and Class C (38.89% and 16.28% respectively) and only some students from Class A provided a correct diagram. 20.93% of Class C gave phenotypic results. Among those who held alternative conceptions (51.43% of Class A, 55.56% of Class B, and 32.56% of Class

C), some demonstrated misunderstanding of what the question asked for by giving the genotypes of dihybrid crosses. Other conceptions included misunderstanding of the genotypes of insects given in the problem, using incorrect diagram or allele symbols, calculating wrong results, and misinterpreting Mendel's experimental results. There were still quite a number of students (5.71% of Class A, 5.56% of Class B, and 30.23% of Class C) who did not provide any response.

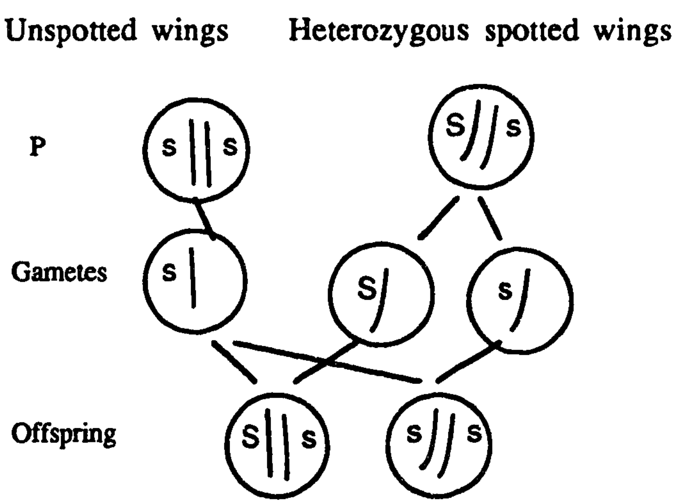
Information regarding interviews with students about these questions (# 7.1 and # 7.2) is not available since the questions were given in the second and the third sessions of written tasks.

The following are examples of students' rationale in arriving at their answers given in the written tasks.

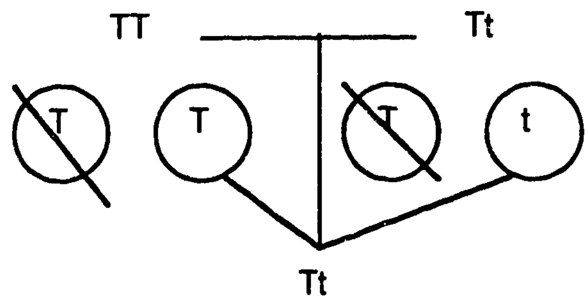
Before instruction, student D (Class A) provided a diagram of a cell and indicated gene symbols outside the diagram. She misunderstood that both the two homologous chromosomes from each parent recombined in an offspring.



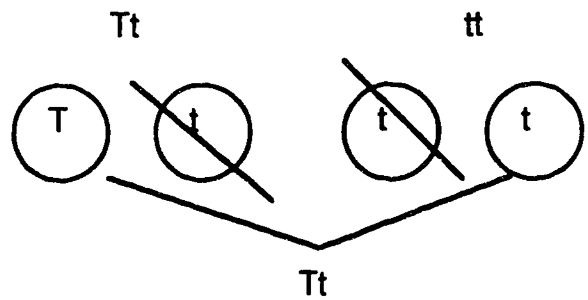
After the instruction, she could illustrate precise understanding of chromosome separation and recombination.



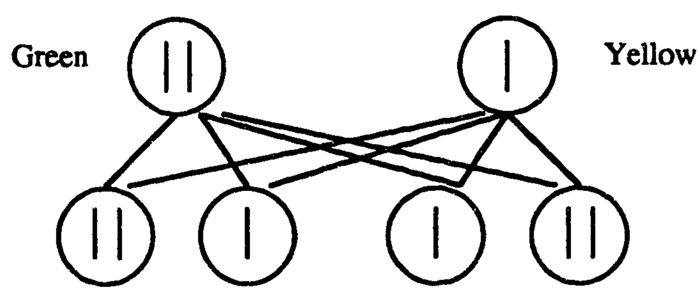
Before the instruction, student E (Class B) thought that we could leave out the identical gamete of both parents as we could do with arithmetic common factors:



After the instruction, she still retained her belief:

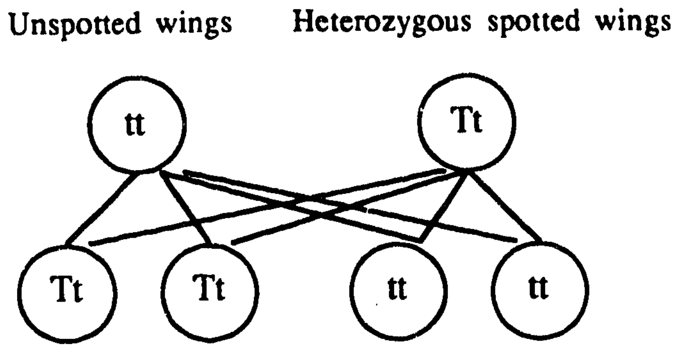


Student F from Class C provided a diagram for the pre-test and presented his misunderstanding in the number of chromosomes involved in the problem:



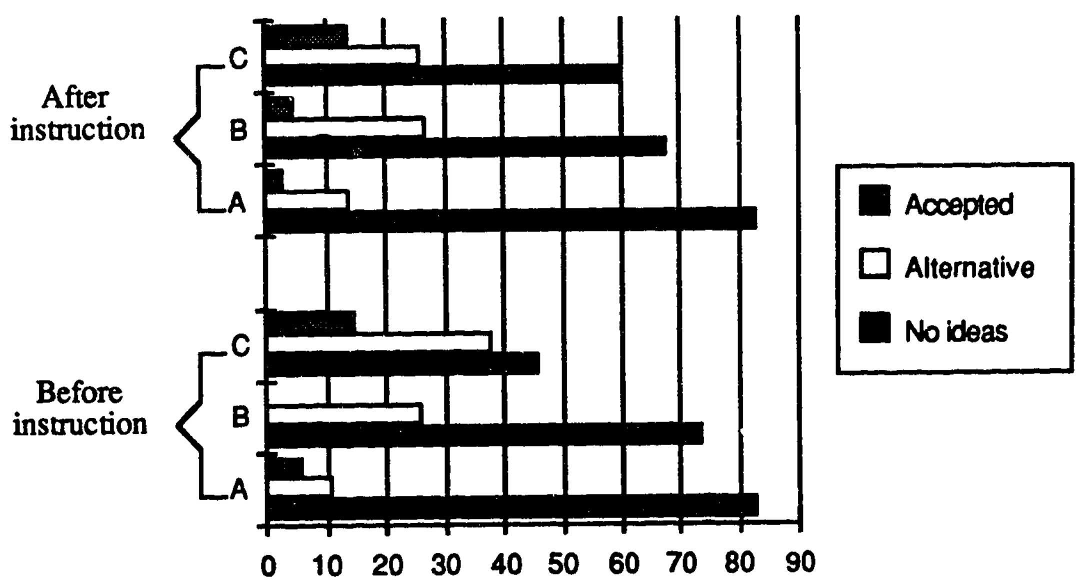
All green - expresses dominant trait

However, after the instruction, he provided a correct letter diagram even though he did not specify any gametal genotypes.



Questions # 8.1 and # 8.2 were adapted from questions developed by Kargbo *et al.* (1980). The questions aimed to probe students' interpretation about some general public notions on heredity. They were asked to predict the height of the son and the daughter of a couple who have considerably different heights. (Q # 8.1 If a tall man and a short woman have a child and this child is a boy, how tall will he be in comparison to his parents when he is fully grown? Why? Q # 8.2 If a child is a girl, how tall will she be in comparison to her parents when she is fully grown? Why?)

Figure 16. The percentage of students' responses to Question # 8.1 during and after instruction.



The accepted responses were:

1. As tall as the father because tall is dominant, or
2. It depends on which is dominant, or
3. It depends on his/ her parents genetic make-up, or
4. Tall or short because only one feature can be expressed, or
5. It depends on many factors that are involved in determining height.

Figure 16 presents the students' viewpoints to Question # 8.1. The first round test results indicated that a majority of students from Class A and Class B (82.86% and 74.29%, respectively) and 46.15% of Class C understood genetic probability. Moreover, three students from Class A and two from Class C realized that environmental factors also play a role in determining how the genes are expressed.

11.43% of Class A, 25.71% of Class B, and 38.46% of Class C believed in alternative reasons such as the inheritance is sexually biased; and a mixing of the parents' traits resulted in a medium height of their children. Interestingly, five students from Class B and one from Class C predicted that the son would be tall because he was in the F_1 generation where Mendel's Law indicated that all the offspring would be tall. Some other students (5.71% from Class A and 15.38% from Class C) did not provide their reasons or did not respond to the question at all.

Approximately the same percentage of students (82.86% from Class A, 67.57% from Class B, and 59.52% from Class C) suggested accepted responses in the post-test. However, their responses demonstrated that they were more cautious in making a prediction. Instead of jumping to a conclusion that tall is dominant, most students tended to consider several variables which were involved in the determination of height such as nutrition, exercise, health, sex-influence, type of dominant gene-complete or incomplete, polygenic nature, and parental genetic make-up.

Similarly, approximately the same percentage of students (14.29% of Class A, 27.03% of Class B, and 26.19% of Class C) retained their alternative beliefs as provided in the pre-test. As usual, some students changed to other alternative interpretations as they responded in the tasks given after the instruction.

Student D from Class A thought that the genes for height were sex-linked in stating that:

> The son will be short because he got a recessive gene from the mother.
>
> Given xy for the father who is tall and
>
> x'x' for the mother who is short
>
> xy + x'x'
>
> x'y
>
> ↓
>
> The son is short because x' can mask y.

Student E from Class B was confused about the ratio of offspring indicated from Mendel's experiment:

> The son will be tall according to Mendel's Law since the ratio of dominant : recessive trait is 3:1.

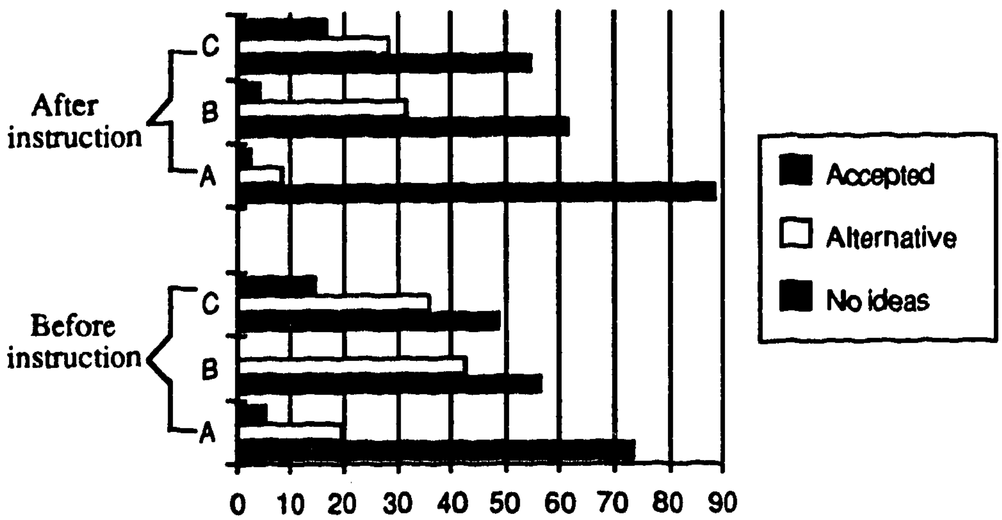
Student F from Class C believed that there is no distinctive trait in animals and a specific allele is expressed unequally in different sexes:

> The son will vary from short to medium because in animals, dominant genes can not totally mask recessive genes and t (allele for shortness) of the father is shorter than t of the mother.

Question # 8.2 asked the students to predict the height of a daughter of the same couple of Question # 8.1. The accepted responses were the same as for # 8.1 including medium to tall because sex also takes part.

Figure 17 illustrates students' conceptions about the height of the daughter. The first-round test results indicated that 74.29% of students in Class A, 57.14% of Class B, and 48.72% of Class C conceived the expected interpretation whereas 20.00% of Class A, 42.86% of Class B, and 35.90% of Class C held alternative conceptions. It is interesting to note that more students believed that the girl would be short to medium because she would take after her mother more. Two students from Class B predicted that the girl would be tall because she was the second child and still in the 2/3 ratio of children who could be tall whereas one student from Class A predicted that she would be short because she was in the F_2 generation where the recessive trait began to appear. Also one student from Class B pointed out that the girl would be short because XX chromosomes took recessive characteristics.

Figure 17. The percentage of students' responses to Question # 8.2 during and after instruction.



After the instruction, slightly more students (88.57% from Class A, 62.16% from Class B, and 54.76% of Class C) conceived the accepted responses. Although the number of students who presented expected interpretations were not much different from those of the pre-test, these students demonstrated their deeper understanding of the concept. In responding to both questions regarding the height, they considered more possibilities before making a decision. Instead of jumping to a conclusion that tall is dominant, most of them mentioned several variables which were involved in the determination of height such as environmental factors, sex-related, type of gene-complete or incomplete dominance, polygenic nature, and parental genetic make-up.

8.57% of students in Class A, 32.43% in Class B, and 28.57% in Class C retained alternative beliefs as presented in the first round. The common alternative conception found in the students' responses was a misinterpretation of Mendel's Law. They believed that children in the F_1 generation would definitely have the dominant trait or the child was still in the ratio of 3:1 dominant to recessive trait.

In the interviews, none of the students from Class A demonstrated alternative conceptions. They were quite clear about genetic probability and other variables which affect phenotypic expression although there were some errors in detail. Nipha, for example, described that:

> If the father is homozygous tall, the son would be tall. But if the father is heterozygous, his son will have the possibility of being tall at 3:1.
>
> His daughter will also be as tall as the son because sex does not affect the height. But environmental factors do.

In contrast, four out of six students from Class B expressed other interesting alternative conceptions. For example, Chana, believed in the inequality of genetic expression in each family as she commented:

> In some family, shortness is a dominant trait, but in other family, shortness is a recessive trait. If shortness is dominant for a family, their children would have more possibility to be short. It depends on each family.

As well, another student from Class B, Anu, demonstrated his confusion about chromosome contribution from each parent and the expression of sex-linked genes. He predicted that both children would be tall because:

> In general, people are tall, especially men. Therefore, tallness should be a dominant trait.

When asked if there was a possibility for the children to be short, he responded that:

> Yes, there is. If they are short, the son will be shorter than the daughter. I remembered that in sex cells, the son gets the Y-chromosome which is half-length (of the X-chromosome), while the daughter gets the full-length (of the X-chromosome). The son has a suppressed recessive trait from his mother that results in an obvious expression of the height. Therefore, if he is tall, he will be taller than his sister (who gets two X-chromosomes), but if he is short, he will be shorter than his sister.

Two out of six students from Class C demonstrated their alternative conceptions. Porn seemed confused about gene contribution and expression as she responded to the questions as follow:

> Porn: The son will be as tall as his father because tall is dominant.
>
> Interviewer: Is it possible for him to be short?
>
> Porn: Yes, it is, if he gets the recessive trait from the mother.

Interviewer: Do you mean that the tall son doesn't get a recessive gene from the mother?

Porn: I think he gets a dominant trait from the father.

Interviewer: So, he doesn't get a recessive gene from the mother?

Porn: Well, he does but it is suppressed. It isn't expressed.

Interviewer: Therefore, how can he be short?

Porn: No, there is no possibility for him.

Nut (Class C) retained his reasoning as it was presented in the pre-test. He described that:

> I remembered that the test item was the same as in the previous test. That's why I gave the same answer. The children in the F_1 generation have no possibility to be short.

When asked why he thought that the children were in the F_1 generation he pointed out that:

> Every problem we used to do, and also our teacher, told us that if the P generation is given, they must be purebred to result in the hybrid F_1 generation. Mendel's law indicated that the F_1 generation would always be all dominant. The children must be tall.

Session III Tasks

Questions # 9 to # 11. Questions # 9 to # 11 were given in the third session of written tasks which was given before the instruction of the dihybrid lesson. These questions were developed to probe specific genetic concepts.

Questions # 9.1 and # 9.2 examined students' knowledge about the dihybrid cross. By specifying the dominant and recessive traits of the beetles, students were asked to predict the genotypes of offspring and explain their solution. (Q # 9.1 What are the possible offspring genotypes of a cross between two beetles which have unspotted wings and are heterozygous for antennae? Q # 9.2 Explain how you get the solution by making a diagram representing chromosomes and genes which are involved in the problem)

Table 9. The percentage of students' responses to Question # 9.1 before and after instruction.

Type of Responses	Percentage of Students					
	Before Instruction			After Instruction		
	Class A (n=35)	Class B (n=36)	Class C (n=43)	Class A (n=35)	Class B (n=37)	Class C (n=42)
*Correct possible genotypic results were given.	28.57 (n=10)	30.56 (n=11)	9.30 (n=4)	71.43 (n=25)	16.22 (n=6)	28.57 (n=12)
Phenotypic results were given.	5.71 (n=2)	11.11 (n=4)	2.33 (n=1)	2.86 (n=1)	0.00 (n=0)	2.38 (n=1)
Incorrect symbols of the alleles were given.	14.29 (n=5)	11.11 (n=4)	13.96 (n=6)	5.71 (n=2)	29.73 (n=11)	0.00 (n=0)
Other alternative conceptions.	40.00 (n=14)	30.56 (n=11)	27.91 (n=12)	8.57 (n=3)	13.51 (n=5)	9.52 (n=4)
No answers.	11.43 (n=4)	16.67 (n=6)	46.51 (n=20)	11.43 (n=4)	40.54 (n=15)	59.52 (n=25)

* = accepted response

Table 9 presents students' responses to question # 9.1. Before instruction of the dihybrid lesson, few students from each class (28.57% of Class A, 30.56% of Class B, and 9.30% of Class C) could provide correct genotypic results. 5.71% of Class A, 11.11% of Class B, and 2.3% of Class C presented phenotypic results whereas 14.29% of Class A, 11.11% of Class B, and 13.96% of Class C demonstrated errors in giving the symbols for alleles either by using two different upper case letters to represent allele symbols for a trait or using the same letters to represent allele symbols for both traits. Many students (40.00% of Class A, 30.56% of Class B, and 27.91% of Class C) held other alternative conceptions including a misunderstanding of the genotypes of insects given in the problem, giving wrong probable results, considering each pair of characteristics separately in a cross, and misunderstanding the segregation and recombination of alleles during reproduction. An example of the latter misunderstanding came from one student in Class B as follows:

tt = unspotted wings Oo = heterozygous antennae

	Oott	Oott
Female	Oo	tt
Male		
Oo	OOoo	Oott
tt	Oott	tttt

Long antennae,	Unspotted wings and long antennae,
Unspotted wings and short antennae,	Unspotted wings

There were 11.43% of Class A, 16.67% of Class B, and 46.51% of Class C who did not give any reason or response.

In the post-test, the question was modified by giving a number of each offspring phenotypes and asking students to determine the most probable genotypes of the parents. (If the results of a different cross of guinea pigs are 21 black-rough, 6 black-smooth, 8 white-rough, and 2 white-smooth, What are the most probable genotype of the parents? Why?) The accepted responses were that both parents should be heterozygous for both traits because:

1. The ratio of offspring phenotypes was about 9:3:3:1, or
2. The offspring have various phenotypes including recessive traits.

It was noticeable that the percentage of students who provided the expected answer increased in Class A and Class C but slightly dropped in Class B. There was an unexpected high percentage of students from Class B and Class C who did not provide any explanation or answer (11.43% of Class A, 40.54% of Class B, and 59.52% of Class C).

2.86% of Class A and 2.38% of class C provided phenotypic results whereas 5.71% of class A and 29.73% of Class B assigned incorrect symbols to the alleles by using the symbols for incomplete dominance (BWRS) or multiple alleles (H^BH^b Rr).

Only 8.57% of Class A, 13.51% of Class B, and 9.52% of Class C predicted incorrect results which included some homozygous dominant or recessive genes, different traits for each parent (BBbb x RRrr or Bb x Rr), and one allele for a specific trait (Br x bR).

Question # 9.2 asked the students to draw a diagram of a cell consisting of chromosomes, and genes involved in a problem to explain how they had arrived at the solution. As shown in Table 10, before instruction of the dihybrid lesson, none of the students could provide an appropriate diagram. However, 22.86% of Class A, 22.22% of Class B, and 6.98% of Class C presented correct symbolic letter diagrams whereas 5.56% of Class B and 2.33% of Class C provided correct Punnett squares.

Table 10. The percentage of students' responses to Question # 9 2 before and after instruction.

Type of Responses	Percentage of Students: Before Instruction Class A (n=35)	Before Instruction Class B (n=36)	Before Instruction Class C (n=43)	After Instruction Class A (n=35)	After Instruction Class B (n=37)	After Instruction Class C (n=42)
*Correct chromosomes/ genes diagram was given.	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)	28.57 (n=10)	0.00 (n=0)	0.00 (n=0)
**Correct symbolic letter diagram was given.	22.86 (n=8)	22.22 (n=8)	6.98 (n=3)	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)
**Correct Punnett square was given.	0.00 (n=0)	5.56 (n=2)	2.33 (n=1)	22.86 (n=8)	13.51 (n=5)	23.81 (n=10)
Alternative explanations	48.57 (n=17)	41.67 (n=15)	27.91 (n=12)	14.29 (n=5)	37.84 (n=14)	4.76 (n=2)
No answers	28.57 (n=10)	30.56 (n=11)	62.79 (n=27)	34.29 (n=12)	48.65 (n=18)	71.43 (n=30)

* = accepted response
** = accepted response as partial understanding

48.57% of Class A, 41.67% of Class B, and 27.91% of Class C demonstrated alternative conceptions. Most students in this group misunderstood the use of symbols for alleles involved in the problem. They used two different upper case letters to represent allele symbols for a trait, for example, they used L to represent long antenna allele and S to represent short antenna allele. Some students used the same letters to represent both traits, for example, they used Tt to represent the alleles for heterozygous long antenna and tt for unspotted wing. Some students could not assign correct genotypes to the insect parents at the first step of a solution process. Other students (27.77% from Class B) thought alleles for different traits separated to different sex cells, and as a consequence, they used a single allele for each trait after fertilization. One student from Class A located both alleles for a trait on a single chromosome. Most students (28.57% from Class A, 30.56% from Class B, and 62.79% from Class C) did not attempt to provide any explanation.

After instruction, only 28.57% of students from Class A provided the expected diagram of genes and chromosomes while 22.86% from Class A, 13.51% from Class B, and 23.81% from Class C presented a Punnett square instead. 14.29% of Class A, 37.84% of Class B, and 4.76% of Class C demonstrated alternative conceptions. Most of them could not specify correct parental genotypes and the others stated a genotype with only one allele for each trait presented. Surprisingly, the number of students who did not give any response increased in every class (34.29% in Class A, 48.65% in Class B, and 71.43% in Class C).

In the interview Krisda (Class A) revealed his confusion about expectation in possibility. As well, he thought that both alleles for each trait were located on a single chromosome. He still used two different upper case letters to represent allele symbols for a trait.

Krisda could not provide the genotypes of parents either in the written task or later in the interview, even when he was guided, because he expected a certain ratio of the offspring.

Interviewer: Now, look. What is the ratio of the offspring?

Krisda: 10 :3 :4 :1.

Interviewer: Is it approximately the same as any ratio of offspring produced from a couple that you have learned about before?

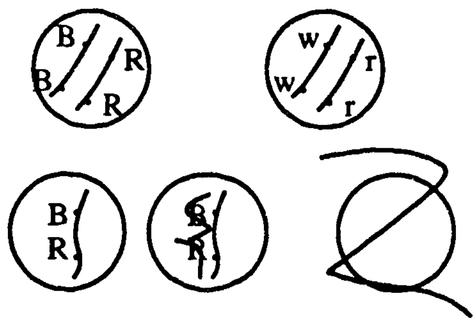
Krisda: No, it isn't.

Interviewer: Not even close?

Krisda: No, I don't think so.

....

When asked to present a diagram of a cross between two heterozygous dihybrid parents. Krisda was not able to complete the process and his diagram was as shown below.

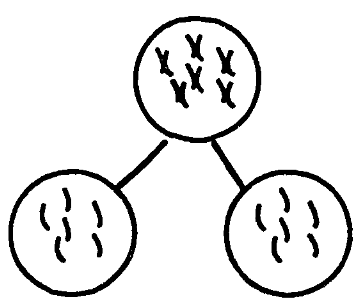


He could not explain why he used Bw for one trait and Rr for another trait, and why B and R were bound together on the same chromosome in a sex cell.

Anu (Class B) could not trace back to the parents' genotypes either. He commented that "I couldn't do it. The item was too long."

He was guided to start from the ratio of the offspring and then tried to use the results of Mendel's experiment. He still could not solve the problem.

He, too, demonstrated an alternative conception when asked to draw a diagram. He conceived that a chromatid that replicated during meiosis was a chromosome itself and each pair of chromosomes stuck together to form an X-shape.



He explained his diagram as follows:

> When the father's and the mother's chromosomes bound together, half of each (chromosome) will stick together to form a pair of chromosomes. And at the formation of a sex cell, each half will separate to each cell and they (the chromosomes) will stick together again when they come to recombine (at fertilization).

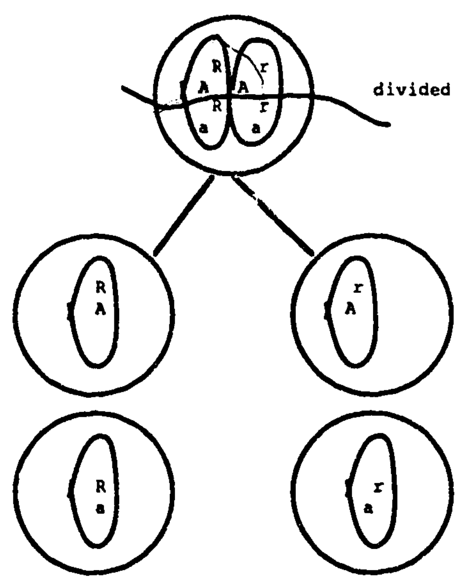
Anu did not locate gene symbols because "I don't know how to do that because all genes are bound together at one place."

In contrast, Nam (Class C) presented the expected parental genotypes with a Punnett square illustration. She described:

> I considered the ratio of the offspring first, then checked the probability and found that the ratio was close to the probability of the offspring produced from a cross between heterozygous dihybrid parents.

She provided a Punnett square to support her solution instead of a diagram of a cell because "there are too many chromosomes, I could not draw a diagram in time."

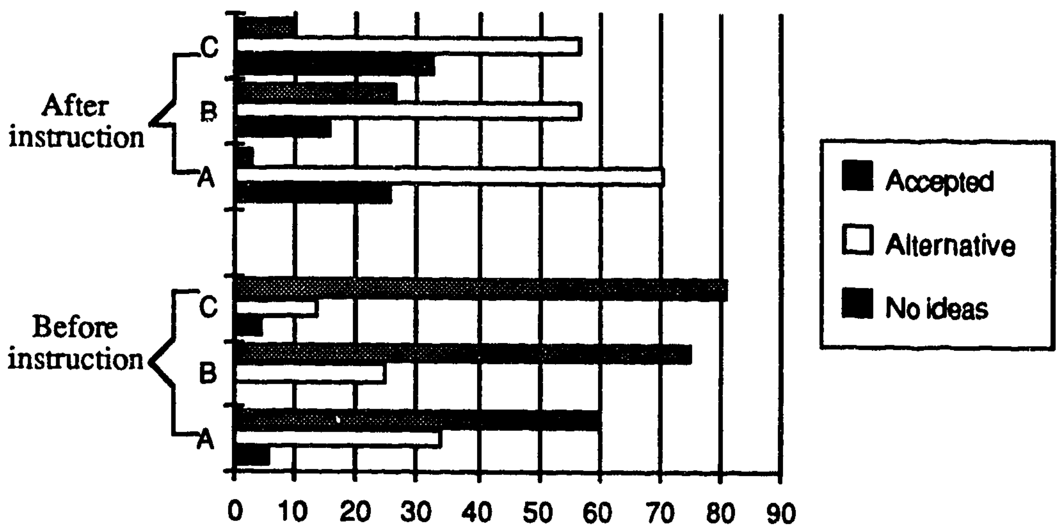
However, her diagram presented at the interview revealed her conception of a "one chromosome" model.



She believed that both alleles for both traits were located on a "pair" of chromosomes. In meiosis the chromosomes split horizontally and vertically to form four sex cells.

Question # 10 probed students' understanding of the term "alleles." By using a situation given in Question # 9, students were asked to give the number of alleles that existed.

Figure 18. The percentage of students' responses to Question # 10.1 before and after instruction.



Q # 10.1 In this problem how many alleles does each gene have? What are they? As shown in Figure 18, before the le on alleles was instructed, very few students (5.71% of Class A and 4.65% of Cl C) suggested the expected answer. The majority (60.00% in Class A, 75.00% in Class B, and 81.40% in Class C) made no attempt to respond or name the alleles while 34.29% of Class A, 25.00% of Class B, and 13.95% of Class C provided alternative conceptions. Those conceptions were a suggestion of each possible pair of alleles, each pair of contrasting alleles, or each pair of homozygous alleles. There were many students who commented that they did not know what an "allele" was.

After instruction, a third or fewer students (25.71% of Class A, 16.22% of Class B, and 33.33% of Class C) suggested that there were three different forms of alleles. Meanwhile, more than half of each class (71.43% of Class A, 56.76% of Class B, and 57.14% of Class C) demonstrated alternative conceptions. The majority of students in this group misunderstood the meaning of an allele. They believed that an allele meant a pair of genes responsible for contrasting traits. Consequently, they provided examples of alleles in a pair or triple either in homozygous or heterozygous forms (i.e. H^PH^g, H^PH^o, H^gH^o; H^PH^P, H^oH^o, H^gH^g; or $H^PH^gH^o$, $H^PH^PH^P$........). There were 2.86% of Class A, 27.03% of Class B, and 9.52% of Class C who did not provide any example or even attempt to answer the question.

Figure 19. The percentage of students' responses to Question # 10.2 before and after instruction.

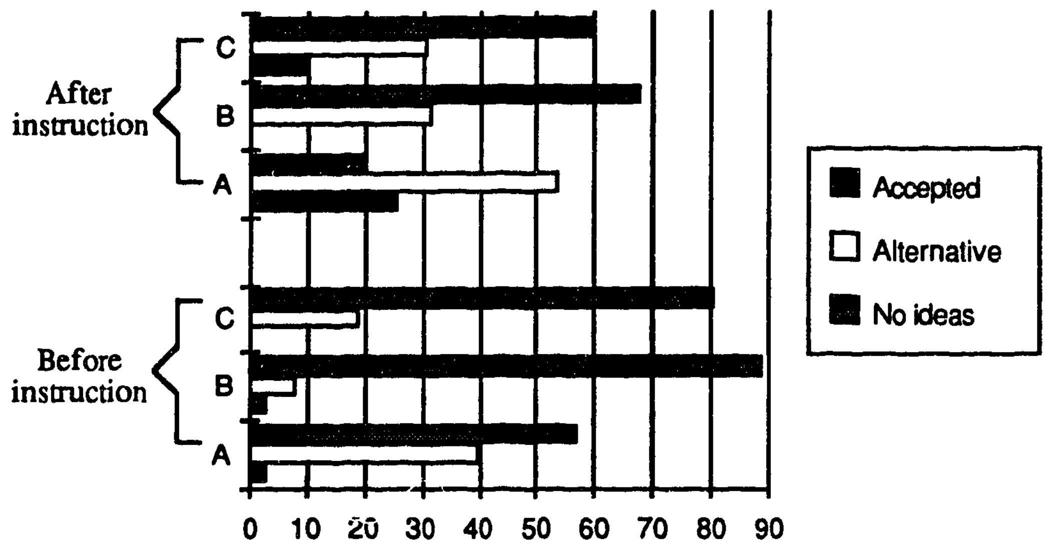


Figure 19 summarizes students' responses to Question # 10.2 (How many alleles for each of these traits are present in a diploid cell? Why?) Before the instruction, only one student from Class A and Class B (2.86% and 2.78%, respectively) could provide the expected response. More than half of each class (57.14% from Class A, 88.89% from Class B, and 81.40% from Class C) made no attempt at responding, whereas the rest (40.00% of Class A, 8.33% of Class B, and 18.60% of Class C) presented alternative conceptions. The answers ranged from one to four alleles with different reasons.

Surprisingly, after the instruction, very few students (25.71% of Class A and 9.52% of Class C) demonstrated their understanding of the concept. Meanwhile, 54.29% of Class A, 32.43% of Class B, and 30.95% of Class C provided alternative conceptions indicating a number of alleles for each gene ranged from 1 to 23. They suggested the possibility of gene combination, possibility of parental gamete types, and chromosome number of human cell as examples of alleles for each gene. One fifth of Class A (20.00%) and more than half of students in Class B and Class C (67.57% and 59.52%, respectively) did not provide their reasons or did not give any response.

Figure 20. The percentage of students' responses to Question # 10.3 before and after instruction.

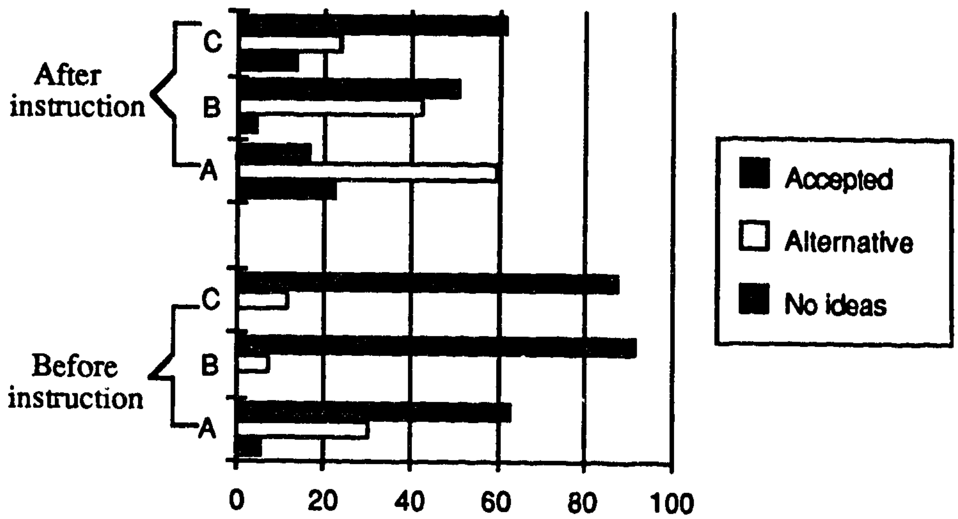


Figure 20 illustrates students' responses to Question # 10.3 (How many alleles for each of these traits are present in any sex cell? Why?) Before the lesson was provided, only two students (5.71%) from Class A suggested that there was one allele for a trait in a sex cell because the pair were separated in meiosis. The majority (62.86% of Class A, 91.67% of Class B, and 88.37% of Class C) did not state the ideas or provide reasons and the rest (31.43% of Class A, 8.33% of Class B, and 11.63% of Class C) indicated the number ranged from 0 to 4. The students who thought there was no allele in a sex cell believed that the alleles must exist in pairs on homologous chromosomes. Consequently, the allele should not exist in a sex cell when homologous chromosomes were separated.

After instruction, there was slight increase in the percentage of students who responded with the expected answer (22.86% in Class A, 5.41% in Class B, and 14.29% in Class C). Incredibly, the percentage of students who held alternative conceptions rose to 60.00% in Class A, 43.24% in Class B, and 23.81% in Class C. This suggests that the more information they got, the more confused they became. Most of this group considered an allele as a pair of genes. As a result, the numbers 0, 1/2, 1, or, 2 were given. The students who responded with "one allele" demonstrated their misunderstanding by suggesting that a pair of homologous genes are equal to one allele. More than half of Class B and Class C (51.35% and 61.90%, respectively) and 17.14% of Class A did not attempt to explain their answers or did not respond to the question.

The conceptual conflicts about alleles is presented below in some interview responses by members from each class.

Khom's (Class A) conflict was evident in his response:

> An allele is a pair of genes located at the same loci on the homologous chromosomes. Consequently, one gene is equal to 1/2 allele. In a diploid cell where 2n chromosomes exist, there is one allele for each trait.
>
> There is no allele in a sex cell because an allele must be in a pair.

As well, Chana from Class B commented that:

> I don't know exactly what an allele is. I think it is dominant and recessive traits which are located at the same loci (of homologous chromosomes). Therefore, I don't know what to answer. I don't know either what a diploid cell is. I heard about it but I can't remember. A sex cell has two alleles because each chromosome matches to form a pair.

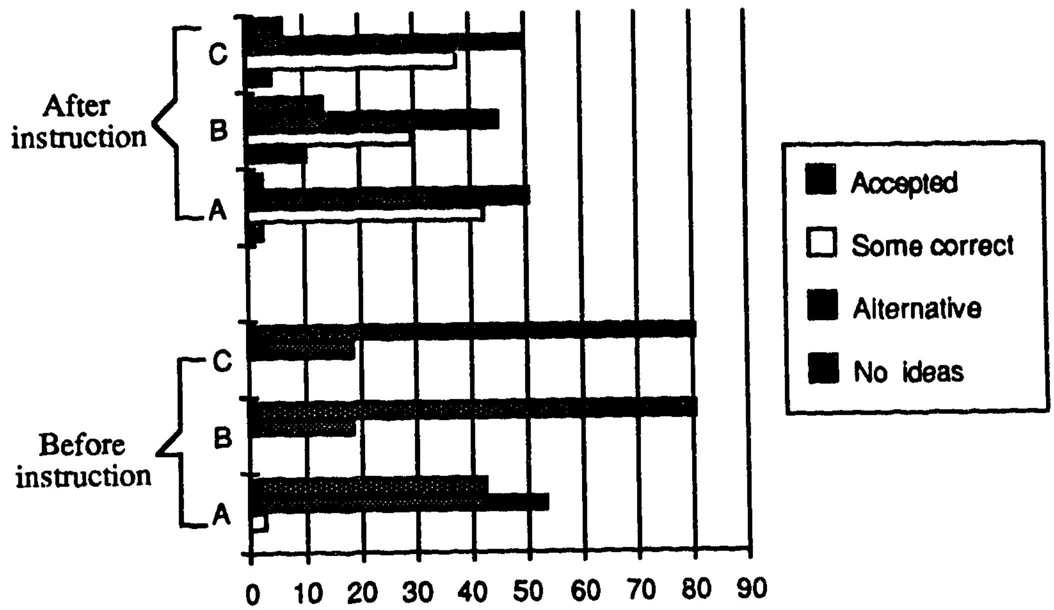
Warun from Class C could not indicate the number of alleles in either a diploid cell or a sex cell. He explained that:

> One allele consists of two genes which are responsible for contrasting traits. I can't remember the meaning of a diploid cell. In the case of hair color of a Mars creature, the gene has six alleles. No, has 3 alleles because there are eight possibilities of (gene) matching. But it must control the same trait and the genes must be in contrast.

The responses to this question suggested that most students had less understanding about the concept of alleles after instruction.

Questions # 11.1 and # 11.2, the last task items, probed students' conceptions about multiple alleles. Given the blood type of a child and a mother, students were asked to list the possible genotypes of the father and the genotypes that the father could not have. (If a child is born with blood type A and the mother has type O. Question # 11.1 List the possible genotypes of the father. Explain your choice. Question # 11.2 List the genotypes that the father cannot be. Explain why.)

Figure 21. The percentage of students' responses to Question # 11.1 before and after instruction.



As shown in Figure 21, before instruction on multiple alleles, none of the students in any class was able to give all of the expected answers. Only one student (2.86%) from Class A suggested one correct possible genotype whereas 54.29% from Class A, 19.44% from Class B, and 18.60% from Class C either gave phenotypic responses or used wrong symbols for the alleles involved in the problem. A majority of students in Class B and Class C (80.56% and 81.40%, respectively) and nearly half (42.86%) from Class A did not attempt to provide any explanation or even respond to the question.

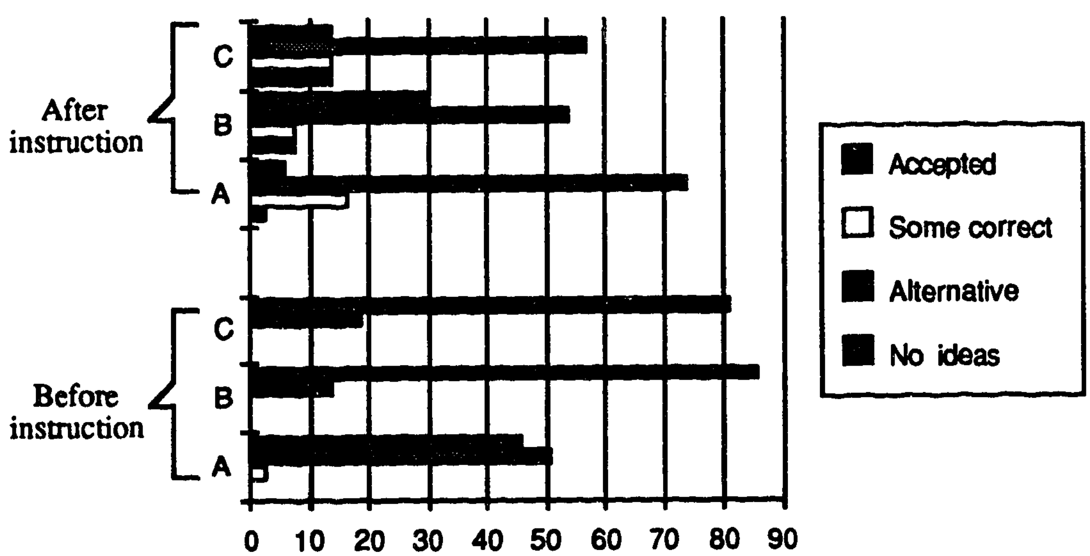
After instruction, very few students (2.86% from Class A, 10.81% from Class B, and 4.76% from Class C) were able to give all the expected answers while a higher percentage (42.86% from Class A, 29.73% from Class B, and 38.10% from Class C) presented only one or two correct genotypes. About half of each class provided either the phenotypic trait, incorrect genotypes, or wrong allelic symbols, for example, PP, PG, Tt ; HP^{o} ; HP nn (n = recessive).

As well, 2.86% of Class A, 13.51% of Class B, and 7.14% of Class C did not respond to the question.

Figure 22 presents students responses to question # 11.2. Before the lesson was given, none of the students from the classes were able to give all of the expected answers. Only one student from Class A (2.86%) presented one of the three correct genotypes. The rest of the students either gave no explanation or answer (45.71% of Class A, 86.11% from Class B, and 81.40% from Class C) or provided unacceptable responses (51.43% of Class A, 13.89% of Class B, and 18.60% of Class C) including phenotypic answers, wrong allelic symbols, or provided incorrect genotypes in their responses.

After instruction, the percentage of students who provided all the expected answers increased slightly (2.86% of Class A, 8.11% from Class B, and 14.29% of Class C). Less than one-fifth of each class (17.14% of Class A, 8.11% of Class B, and 14.29% of Class C) suggested only one or two correct genotypes. The majority (74.29% from Class A, 54.05% from Class B, and 57.14% from Class C) incredibly presented some alternative conceptions. They pointed out either phenotypic traits, unacceptable genotypes, or still used incorrect allelic symbols as shown above. Other students, 5.71% from Class A, 29.73% from Class B, and 14.29% from Class C, did not explain their reasons or did not even attempt to answer the question.

Figure 22. The percentage of students' responses to Question # 11.2 before and after instruction.



Some interview information illustrated that most students had difficulties in comprehending the concepts of multiple alleles. These difficulties were expressed in a dialogue with the following students.

Khom (Class A) commented that "I am so confused about how these three genes exist because they should be located on three chromosomes."

Neither could Khom assign accepted symbols for those alleles although he had partial understanding of what genotypes the father should or should not be as he described that:

> The father could have only H^p if he is homozygous. But if he is heterozygous he could be Po.
>
> He could not have H^g or H^o if he is homozygous or GP/Go if he is heterozygous.

He was asked to write a genotype of what he meant by homozygous H^p but he responded that:

> I can't. This symbol H^p was given in the problem and I just know that the father must be the homozygous of H^p or heterozygous of Po to produce a purple hair offspring.
>
> (Khom missed the class when the lesson on multiple alleles was instructed.)

In contrast, Anu (Class B) demonstrated his understanding of how to assign the gene symbols and was able to give partially correct possible genotypes. He was still confused about the conception of incomplete dominance as indicated by his comments:

Anu: The father must be H^pH^o and H^pH^p but he could not be H^pH^g....because since these two features are incomplete dominant, the color would be half of each.

Interviewer: Whose color, the father or the offspring?

Anu: The offspring. If the father is H^pH^g and the mother is H^oH^o, the offspring would have a mixed color because they (H^p and H^g) are incomplete dominant. They must express together.

Interviewer: Do you mean that H^p and H^g are bound together in a sex cell?

Anu: I don't think they are, but ...(pause)..I don't know.

Similarly, Warun (Class C) could explain what the genotypes could be but he, too, comprehend incomplete dominance as a mixing of genes. This conceptual conflict was evident in his response:

> Purple hair could be two possible genotypes, H^PH^O or H^PH^P. In this case, the mother has orange hair, then the offspring must be H^PH^O. Therefore, the father must have either H^PH^P or H^PH^O genotype. He (the father) could not be H^PH^g because in this case of incomplete dominance, it (the offspring) must have the other color.

Summary of Alternative Conceptions Held by Students

One purpose of this study is to identify some alternative conceptions held by grade 11 Thai students. Therefore the first research question is:

What are the common alternative conceptions that grade 11 students hold about heredity prior to and following instruction?

The question is broken into two specific questions:

1. What are the preconceptions that the students hold before instruction?

2. What are the alternative conceptions which arise as a result of instruction?

On the basis of the above findings, the answers are summarized under the headings of general public notions on heredity and specific genetic concepts.

Preconceptions about general public notions on heredity

In the study conducted, the common preconceptions found to be used by grade 11 Thai students before instruction were:

1. Concerning the difference between environmental and hereditary characteristics (Questions # 2.1 and # 6.1), more than half of the students in this study demonstrated understanding of the concepts. Only a few students believed that some environmentally produced characteristics could be passed on to the next generation. Some students believed that genetic factors had no effect on athletic skills.

2. Concerning the effect of time on the possibility of inheritance of acquired characteristics (Questions # 2.2 and # 6.2), similar to questions # 2.1 and # 6.1, many students had correct understandings of the concepts. However, some students who believed that phenotypic change might not be immediately passed on to the next generation held the idea that those changes might be transmitted later.

3. Concerning the probability in inheritance (Question # 3.1), less than half of the students exhibited consideration of accepted genetic principles for their prediction. Four common alternative conceptions found to be used by the students were:

(a) All the offspring born of a couple of dominant and recessive traits will have the dominant trait.

(b) Male parents often had dominant features.

(c) Female parents contributed more.

(d) Black color was definitely dominant to white color.

4. Concerning the equality of genetic contribution of each parent in sexual reproduction (Question # 3.2), very few students conceived the accepted ideas. Nearly half of them believed that the parent with a dominant trait would have greater influence on the characteristics of the offspring. As well, about one third of the students believed in the inequity of the parents' contribution.

5. Concerning the likeness and variation within a family (Questions # 4.1 and # 4.2), almost all of the students had some ideas about why there are likenesses between siblings and about half of them demonstrated partial understandings about why siblings could never be exactly alike. Three alternative conceptions held by the students were:

(a) Children inherited different amounts of genes, chromosomes, or characteristics.

(b) Children inherited different genes or chromosome orders.

(c) Time and environment were the major sources of variation.

6. Concerning the relationships between the height of a son and a daughter and the height of their parents (Questions # 8.1 and # 8.2), more than half of the

students understood genetic probability. Three common alternative conceptions found to be used by the students were that:

(a) The inheritance is sexually biased, for example, a son would more likely take after his father.

(b) All or two thirds of the offspring born of a couple of a dominant and a recessive trait will have the dominant trait.

(c) The recessive trait begins to appear in the F_2 generation.

Preconceptions about specific genetic concepts

Students preconceptions identified through analysis of the written tasks under the heading of specific genetic concepts were:

1. Concerning the knowledge about the genes (Questions # 5.1, # 5.2, and # 5.3), more than half of the students presented a basic correct definition of the genes. Slightly more students understood that genes were located on the chromosomes. Almost all students had no ideas about how genes functioned. Only one student explained that genes "control" the body growth through chemical codes. The alternative conceptions used by the students were:

(a) A gene was a gamete, a cell, one type of chromosome, or a trait itself.

(b) A gene was a protein compound.

(c) Genes were located in the growing parts of the body.

(d) Genes had no specific location, but they were present only during reproduction.

(e) Inheritance occurred through an exchange of parental genes during the crossing over of chromosomes.

2. Concerning the segregation of alleles during meiosis (Question # 7.1), few students demonstrated understandings of the concept. Most of them understood that a pair of alleles for a particular trait were present in a gamete. Some students could not assign correct allele symbols for a trait.

3. Concerning problem solving on the monohybrid cross (Question # 7.2), some students had a correct understanding of the concept. A larger portion held alternative conceptions including:

(a) Parental genotypes assigned incorrectly.

(b) Segregation of genes to sex cells misunderstood.

(c) Symbols used to represent alleles for a trait misunderstood.

(d) A rationale involving phenotypes used to arrive at the answer.

(e) A cell diagram to explain the results unable constructed.

4. Concerning problem solving on the dihybrid crosses (Questions # 9.1 and # 9.2), about one fourth of the students could provide correct genotypic results. Other students had alternative conceptions similar to the monohybrid problem. Those conceptions were:

(a) Incorrect parental genotypes assigned.

(b) Segregat[illegible] and recombination of alleles during reproduction misun[illegible]d.

(c) Symbo[illegible] to represent alleles for a trait misunderstood.

(d) A rationale involving phenotypes used to arrive at the answer.

(e) Each pair of characteristics considered separately in a cross.

(f) A cell diagram to explain the results unable constructed.

5. Concerning the knowledge about the alleles (Questions # 10.1, # 10.2, and # 10.3), most of the students had no ideas about the concepts. Very few students provided the accepted responses. Some students thought an allele was a pair of genes responsible for contrasting traits.

6. Concerning problem solving on the multiple alleles (Questions # 11.1 and # 11.2), most of the students had no ideas about the concepts. Very few students could suggest some expected responses. Some of them provided phenotypic results. Alternative conceptions found to be used by the students were misunderstandings of using symbols to represent alleles for a trait.

Alternative conceptions about general public notions on heredity which arose as a result of instruction.

After instruction, a number of students still held the same conceptions as they did before instruction. Also, it was found that several alternative conceptions emerged as a result of instruction. Those conceptions were as follows.

1. The concept of the difference between environmental and hereditary characteristics.

(a) There were two alleles, tail and tailless, which control the existence of animal tails. If parents were hybrid, there was a possibility to get some tailless offspring.

(b) There were two alleles which control running skill, therefore, fast running ability was either a dominant or recessive trait.

(c) There was no genetic change because fast running ability was classified as a discontinuous trait, therefore, environmental factors had less effect on the skill.

2. The concept of the effect of time on the possibility of inheritance of acquired characteristics.

(a) There were two changes in inheritance - continuous and discontinuous changes. Continuous change could affect the genes. As a result, if the couple of each generation continued practice, there was a possibility to have automatically fast running children.

(b) According to the law of "use and disuse", children could be automatically good runners because this ability had been practiced continuously over time.

(c) A child's body structure would "improve" dramatically as a result of being a descendant of athletes (although the child would or would not be born with automatically good running skills).

(d) The crossing over of chromosomes may result in a genetic make-up, therefore if this happens, children could possibly be automatically good runners.

3. The concept of probability in inheritance.

(a) A couple of dominant and recessive traits would definitely produce dominant trait offspring.

(b) One out of four offspring produced in the F_2 generation would have a recessive trait.

(c) A couple of black and white mice might produce a recessive trait offspring if black and white were incomplete dominant.

4. The concept of equality of genetic contribution of each parent in sexual reproduction.

(a) In animals, a father could transmit hereditary characteristics better than a mother because there were four different types of sperms produced each time whereas there was only one egg.

(b) A father usually had homozygous genes.

5. The likeness and variation within a family.

(a) The F_1 generation should have the same phenotypes.

(b) Polygenes and incomplete dominant genes were the major factors of variation within a family.

(c) Variation within a family was a continuous variation, therefore, there were some likenesses and some differences between siblings.

(d) Genes expressed differently each time.

(e) Genes which were bound into each different sex cell did not control the same trait.

(f) The crossing over of chromosomes during fertilization caused variation between siblings.

6. The relationships between the height of a son and a daughter and the heights of their parents.

(a) The genes for height were sex-linked.

(b) A phenotypic expression of a hybrid trait was inferior to a homozygous dominant trait.

(c) Genetic expression in each family was not constant, for example, shortness might be a dominant trait for one family but a recessive trait for another family.

(d) Dominant genes were more powerful than recessive genes.

Alternative conceptions about specific genetic concepts which arose as a result of instruction.

Alternative conceptions found to have arisen as a result of instruction were:

1. The knowledge about the genes.

(a) A gene was a protein compound.
(b) A pair of genes for a particular trait were located on a single chromosome.
(c) Genes were usually bound together at a centromere. They would line up on a chromosome only during the processes of cell division.
(d) A genotype was a characteristic itself but a phenotype was an indicator of characteristics to be expressed.

2. Problem solving on the monohybrid cross.

(a) F_1 must have a dominant trait.
(b) Both alleles for a trait were located on a single chromosome.
(c) Incapability of using a cell diagram to explain the results.

3. Problem solving on the dihybrid cross.

(a) Incapability of using a cell diagram to explain the results.
(b) Using the symbols for incomplete dominant or multiple alleles to represent complete dominant alleles, for example, BW or H^BH^b = heterozygous black dog.
(c) Misunderstanding of separation and recombination of chromosomes during cell division.

4. The knowledge about alleles.

An allele was a pair of genes responsible for contrasting traits.

5. The knowledge about the multiple alleles.

(a) Incapability of using accepted symbols to represent alleles involved in a problem.

(b) Blending forms of inheritance (incomplete-dominance) involved a mixing of genes; therefore, the father with a genotype H^PH^g could not give a purple-haired offspring.

Summary of Changes and Stability in Students' Conceptualizations

Changes of responses of individual student regarding general public notions and specific genetics concepts are summarized into five patterns after Engel Clough *et al.* (1987) as shown in Table 11.

1. Consistent use of accepted conceptions. More than half of the students consistently used accepted scientific ideas in responses to problems related to general public notions on the following concepts.

2.1 The difference between acquired characteristics and purely inherited traits. (Suppose the tails of two dogs were cut short at a veterinary clinic when they were just two weeks old. If these two dogs later have a puppy, what will be the length of the tail of this puppy? Explain why.)

4.1 The likeness within a family. (Can you explain why are children at the same family frequently look like one another?)

6.1 The possible inheritance of developed human skills. (A couple had trained hard to become good runners, though they were not particularly proficient naturally. Would their children be automatically good runners?)

Students' responses tended to be short and simple in the pre-test. Their detailed explanation given in the post-test indicated development toward precise understanding of the concepts.

For scientific genetic knowledge, students performed well on items # 5.1 (What are genes?) and # 5.2 (Where are they located?). These questions required only factual knowledge.

Table 11. Summary of changes and stability of thinking in individual before and after instruction.

Item No.	Consistent use of accepted conceptions			Consistent use of alternative conceptions			Change from alternative to accepted conceptions			Change from alternative to other alternative conceptions			Change from accepted to alternative conceptions			No responses at pre- and / or post-test		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
2.1	80.0	86.5	95.2	2.9	0.0	0.0	17.1	8.1	2.4	0.0	0.0	0.0	0.0	2.7	0.0	0.0	2.7	2.4
2.2	40.0	43.2	64.3	11.4	27.0	0.0	25.7	13.5	7.1	8.6	5.4	2.4	14.3	5.4	21.4	0.0	5.4	4.8
3.1	45.7	24.3	40.5	0.0	2.7	0.0	28.6	10.8	19.0	5.7	21.6	4.8	11.4	24.3	28.6	8.6	16.2	7.1
3.2	2.9	2.7	4.8	45.7	29.7	31.0	34.3	21.6	19.0	11.4	32.4	26.2	5.7	8.1	9.5	0.0	5.4	9.5
4.1	88.6	70.3	69.0	0.0	0.0	0.0	2.9	5.4	2.4	0.0	0.0	0.0	5.7	5.4	4.8	2.9	18.9	23.8
4.2	57.1	35.1	23.8	5.7	0.0	4.8	25.7	21.6	19.0	2.9	10.8	7.1	2.9	10.8	7.1	5.7	21.6	38.1
5.1	57.1	67.6	54.8	5.7	2.7	0.0	28.6	24.3	35.7	0.0	2.7	2.4	5.7	2.7	4.8	2.9	0.0	2.4
5.2	77.1	94.6	85.7	0.0	0.0	0.0	5.7	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.1	2.7	14.3
5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0
6.1	77.1	57.1	60.5	0.0	5.7	2.6	11.4	17.1	18.4	2.9	5.7	5.3	8.6	11.4	13.2	0.0	2.9	0.0
6.2	40.0	37.1	34.2	17.1	25.7	13.2	17.1	11.4	26.3	5.7	2.9	7.9	20.0	20.0	10.5	0.0	2.9	7.9
7.1	0.0	0.0	0.0	62.9	75.8	7.7	14.3	12.1	2.6	14.3	0.0	7.6	0.0	6.1	0.0	8.6	6.1	82.1

Item No.	Consistent use of accepted conceptions			Consistent use of alternative conceptions			Change from alternative to accepted conceptions			Change from alternative to other alternative conceptions			Change from accepted to alternative conceptions			No responses at pre- and / or post-test		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
7.2	20.0	18.2	0.0	8.6	18.2	5.1	22.9	24.2	2.6	20.0	24.2	2.6	20.0	9.1	2.6	8.6	6.1	87.2
8.1	71.4	54.3	36.8	2.9	8.6	2.6	11.4	11.4	23.7	2.9	11.4	13.2	8.6	11.4	5.3	2.9	2.9	18.4
8.2	54.3	42.9	23.7	2.9	8.6	2.6	28.6	17.1	28.9	2.9	14.3	18.4	5.7	14.3	7.9	5.7	2.9	18.4
9.1	20.0	11.1	7.1	0.0	5.6	2.4	40.0	2.8	11.9	14.3	5.6	7.8	5.7	25.0	0.0	20.0	50.0	73.8
9.2	14.3	8.3	0.0	0.0	8.3	0.0	31.4	0.0	7.1	2.9	11.1	2.4	0.0	16.7	0.0	51.4	55.6	90.5
10.1	11.4	0.0	7.1	8.6	0.0	2.4	2.9	5.6	7.1	14.3	8.3	4.8	31.4	2.8	9.5	31.4	83.3	69.0
10.2	11.4	0.0	4.8	0.0	2.8	9.5	14.3	2.8	0.0	11.4	2.8	0.0	8.6	0.0	4.8	54.3	91.7	81.0
10.3	2.9	0.0	4.8	8.6	0.0	4.8	14.3	0.0	0.0	8.6	8.3	0.0	0.0	0.0	4.7	62.9	91.7	85.7
11.1	2.9	0.0	0.0	22.9	13.9	7.1	17.1	2.8	9.5	5.7	0.0	0.0	0.0	0.0	0.0	51.4	83.3	83.3
11.2	0.0	0.0	0.0	0.0	8.3	7.1	2.9	0.0	4.8	2.9	0.0	0.0	2.9	0.0	0.0	91.4	91.7	88.1

(adapted from Engel Clough *et al.*, 1987)

2. Consistent use of alternative conceptions. The task item in which the highest percentage of students consistently used alternative conceptions was # 7.1. (What are the genotypes of each possible gametes produced by a pea plant that is heterozygous green pod? Explain why.) The most common mistakes were that they suggested both alleles of a pair for a gamete. The results indicated that students failed to recognize the relationship between meiosis and problem solving in genetics. They conceived problem solving as an arithmetic algorithm.

Although the percentage of students from Class C who consistently used alternative conceptions seemed to be low, 58.97% of them did not provide any responses in the pre-test but revealed some alternative conceptions in response to the post-test.

Other task items in which many students demonstrated consistent use of alternative conceptions were:

3.2 The equality of genetic contribution by each parent in sexual reproduction. (Which one of the parent mice do you think will have a greater influence on the characteristics of the offspring?) Students believed that dominant genes were more powerful than recessive genes. As a result they retained their beliefs that the parent who had dominant traits would have greater influence on an offspring's characteristics.

6.2 The effect of time on the possibility of inheritance of developed skills. (If the children of this family practiced hard over several generations, would you get automatically fast runners in about 200 years? Why?) Some students continue to believe that gene factors had no effect on human skills whereas some of them retained their belief that phenotypic change might be transmitted to descendants in the future generations.

For specific genetic knowledge, a high percentage of students consistently used alternative conceptions in response to question # 11.1. They were asked to predict the possible genotypes of the father, in problem solving about multiple alleles. (If a child is born with blood typ ^ and the mother has type O blood, list the possible genotypes of the father. Explain y choice.)

Students could not assign accepted allele symbols or just provide some possible phenotypes of the father. 22.86% of Class A, 30.56% of Class B, and 35.71% of Class C who made no attempt at responding in the pre-test, presented alternative conceptions in the post-test.

3. Change from alternative to accepted conceptions. A number of students demonstrated their development toward accepted scientific ideas on the following concepts:

#3.2 The equality of genetic contribution by each parent in sexual reproduction. (Which one of the parent mice do you think will have a greater influence on the characteristics of the offspring?) In responding to this question, one group of students shifted to a more accepted scientific viewpoint whereas another group retained their beliefs as they did prior to instruction.

#4.2 The variation within the same family. (Why are children at the same family not identical?)

#5.1 Knowledge about genes. (What are genes?)

#7.2 Problem solving on the monohybrid cross. (In garden peas, green pod color is dominant to yellow. Give the resulting possible genotypes if a pea plant that is heterozygous is crossed to a pea plant that is homozygous green pod.)

4. Change from alternative to other alternative conceptions. The concepts in which high percentages of students change their alternative conceptions to other alternative conceptions were:

#3.2 The equality of genetic contribution by each parent in sexual reproduction. (Which one of the parent mice do you think will have a greater influence on the characteristics of the offspring?) Many students who believed in the inequality of parents' contribution for various reasons changed to believing that the parent with the dominant trait would have greater influence.

#7.2 Problem solving on the monohybrid cross. (The post test question was modified to "In beetles, wings with spots are dominant to wings without spots. What are the possible offspring genotypes of a cross between a beetle that has unspotted wings and a beetle that is heterozygous spotted wings? Why?) The popular misunderstanding of this concept was that students assigned two heterozygous genes to represent the genotype of a parent who has a recessive trait. This might be because most of the examples they had been studying were the crosses between two hybrid parents or because the pre test question asked about a cross between a hybrid parent and a homozygous dominant parent.

In response to Question # 7.2, there were 33.33% of students from Class C who did not attempt to provide any responses in the pre-test but demonstrated alternative conceptions in the post-test.

5. Change from accepted to alternative conceptions. There were many students who held accepted conceptions at the very beginning but presented the opposite trend in response after instruction. After they had learned that each feature is controlled by a pair of genes or there is a possibility for mutation of genes, they then reasoned that there were two genes responsible for an existence of tails - one for tailness and another one for taillessness. Therefore, in response to Question # 2.2, (Do you think that if a scientist bred the mice with the chopped-off tail again and again, would he get the tailless mice? Explain your answer.), these students changed their ideas that over several generations there might be some mice with no tails when two hybrid mice mated. Other students believed that continuous change would affect the genes and that there might be an adjustment of chromosomes when they learned that there were two types of variation - continuous and discontinuous.

In response to Question # 3.1 (A student placed a white female guinea pig in a cage with 3 male guinea pigs-one white and two black. Later the female gave birth to a white offspring. Which of the males could be the father of the offspring, if black color is dominant to white?), some students, who exhibited consideration of accepted genetic principles for their prediction of the colors of the offspring, later conceived that the black male mouse who has a dominant trait must produce black offspring.

Students from different classes demonstrated different alternative conceptions in response to Question # 6.2 (If the children of this family practiced hard over several generations, would you get automatically fast runners in about 200 years? Why?) after instruction. Students from Class A believed that although the children could not be automatically fast runners, they would inherit the strong body structure which their parents gained from athletic training. Students from Class C suggested that continuing practice may result in genetic change. The common alternative conception for all three classes was that genetic factors have no substantial role in human skills.

In response to Question # 10.1 (In this problem how many alleles does each gene have? What are they?), many students who provided the correct number of alleles for a gene before instruction, demonstrated their alternative conceptions after instruction when they gave examples of each allele. They provided examples of an allele in a pair or triple forms. It is interesting that 20.00% of Class A, 44.44% of Class B, and 36.11% of Class C, who did not provide any response in the pre-test, presented alternative conceptions in the post-test.

Many students from Class B and Class C did not attempt to respond to the question both before and after instruction. More than 25% of Class C did not give any response to Questions # 7.2 (problem solving on the monohybrid cross), # 9.1, # 9.2 (problem solving on the dihybrid cross). About 50% and more of Class B and Class C did not attempt to respond to Question # 10.2 and # 10.3 (the number of alleles in a diploid and a haploid cell).

All students from each class (except two from Class A) had no ideas, both before and after instruction, on item 5.3-how genes function in heredity. They just stated that genes control hereditary transmission from parents to offspring. It is not surprising, however, since this concept is not introduced at this level and the concept might be too abstract and beyond the imagination of this age group.

Students' Responses to Session V Tasks

Questions used in the fifth session of written tasks were identical to those questions used in the fourth session including Questions # 7.1 and 7.2 used in the third session. A concept map and all questions # 2.1 to # 11.2 were given to determine students' retention of ideas four months after the instruction of the genetic unit.

Students' responses to the tasks were grouped into five levels of understanding. The criteria were adapted from the concept evaluation scheme suggested by Westbrook and Marek (1991, 1992). Degrees of understanding were classified as follows.

Complete understanding (CU). The student's response contains all information necessary to explain an event or situation in a scientific way.

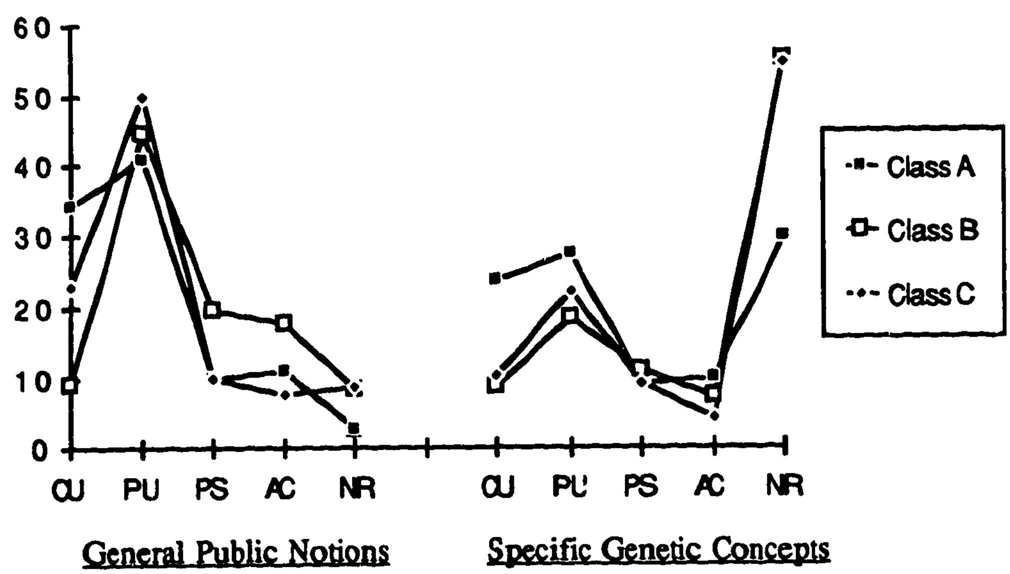
Partial understanding (PU). The student's response contains some accepted scientific ideas. No incorrect information includes in the response.

Partial understanding with specific alternative conception (PS). The student's response includes correct information and some alternative conception.

Alternative conception (AC). The student's response demonstrates a complete alternative conception of the idea.

No understanding (NU). The student's response consists of irrele‵ ınt remarks, the question repeated, or the page left blank.

Figure 23. Summary of Mean of Students' Responses to Retention Tasks (in percent).



The comparisons between groups indicate that the higher percentage of students in Class A had complete understanding on the tasks probing both general public notions and specific genetics concepts, as well as alternative conceptions in relation to specific genetic concepts. In contrast, the higher percentage of students in Class B demonstrated alternative conceptions in relation to general public notions.

The highest percentage of students in Class C had partial understanding in relation to general public notions and they held the least alternative conceptions in both areas of conceptual knowledge investigated. However, higher percentage of students from Class B and C did not give any responses to the items in both areas.

On average students were doing well in response to questions related to general public notions but also persisted in their alternative conceptions. Students had difficulties on specific genetic concepts judging by the high percentages of each group which did not give responses to the questions as well as by the low percentages of complete understandings. Those concepts were abstract and needed more theoretical basis, thus the students could hardly remember them. Students of Class A demonstrated better understanding over all, followed by students of Class C, and then Class B. These results indicated that the conceptual change teaching approach class (Class A) had less memory decay than the current teaching approach classes. (See more details in Appendix 6.)

Comparison of the Effects of the Different Instructional Approaches

The third research question was to determine "How effective are the designed lessons, aimed at developing students' appropriate conceptions?" In this session, three areas of conceptual understanding: propositional knowledge or conceptions of relationships between concepts, general public notions related to genetics principles, and specific genetics knowledge were considered separately.

To find out how individual student conceptions of relationships between concepts are affected by different teaching approaches, each student's concept map scores before, during, and after instruction, and his/her retention were compared in percents as illustrated in Figure 24. Stuart's (1985) marking scheme was modified to serve as the guide for scoring the students' concept maps (see Appendix 2).

Series of ANOVA's were done for Map I through Map V by class as shown in Table 12. The analyses indicate that before instruction (Map I) there was a significant difference between the three groups except between Class A and Class B. The discrepancies between the performances of the classes indicate that the comparability of the groups cannot be established on this basis. However, the results illustrate different trends in students' patterns of knowledge construction. The students in the conceptual change approach appeared to be more consistent in their ability to construct propositional knowledge as new concepts were added into each following session. The students from Class B (current approach) tended to lose organizational structure of storage concepts and appeared to turn to a pattern of rote-mode learning as the scores decreased in the post test. In contrast, students from Class C who also were taught by the current approach illustrated the lowest degree of structure in cognitive network. This group of students maintained their lack of ability to relate concepts and form meaningful clusters throughout the course of study.

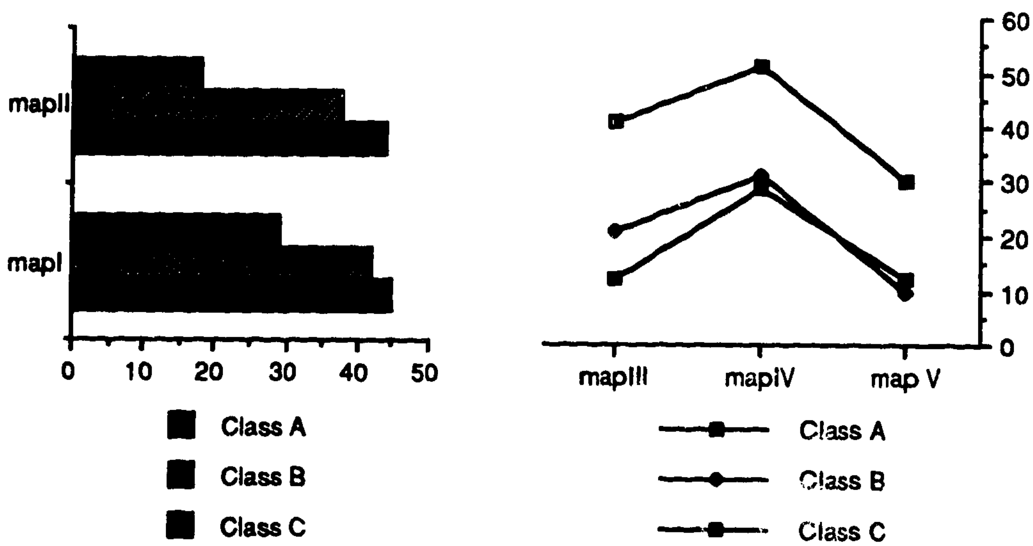


Figure 24. Comparison of Mean Concept Map Scores across Five Sessions (in percent).

(* Map I and Map II were pre-concept mapping consisted of six and nine terms respectively, Map III-V consisted of twelve identical terms)

The results of a retention test demonstrate memory decay of each group where the highest percentage of loss occurred for Class B, followed by Class C, and then Class A. An analysis of variance indicates that although there was not a significant difference in the mean scores between Class A (conceptual change approach) and Class B (current approach) at the very beginning, there have found to be differences between the two groups immediately after instruction and the retention period. Class C had the lowest scores (except for the retention test) and there were significant differences to Class A across the tests. There were significant differences in the mean scores between Class B and Class C on the first three sessions (Map I through Map III) but no differences between the two groups on the post (Map IV) and retention tests (Map V). Thus, it may be concluded that the conceptual change approach does result in the stability of conceptual organization where new concepts are assimilated to the existing structure.

Table 12a. Results of series of one-way ANOVA's of concept map scores by group.

Source	D.F.	SS	MS	F-Ratio	P value
Map I					
Between groups	2	5933.2989	2966.6494	5.8315	.0039
Within Groups	112	56977.9393	508.7316		
Total	114	62911.2382			
Map II					
Between groups	2	14226.5663	7113.2831	24.4150	.0000
Within Groups	106	30883.0178	291.3492		
Total	108	45109.5841			
Map III					
Between groups	2	16478.5008	8239.2504	33.0563	.0000
Within Groups	111	27666.6194	249.2488		
Total	113	44145.1202			
Map IV					
Between groups	2	10575.7948	5287.8974	17.0632	.0000
Within Groups	111	34398.8767	309.8998		
Total	113	44974.6715			
Map V					
Between groups	2	7528.6395	3764.3197	15.0167	.0000
Within Groups	95	23814.1638	250.6754		
Total	97	31342.8033			

Table 12b. Significant differences between groups on concept map scores.

Variable	Mean	Group	Class C	Class B	Class A
Map I	28.9028	Class C			
	41.6986	Class B	*		
	45.3066	Class A	*		
Map II	17.7356	Class C			
	38.2574	Class B	*		
	43.9280	Class A	*		
Map III	11.7737	Class C			
	21.1806	Class B	*		
	40.7163	Class A	*	*	
Map IV	29.0931	Class C			
	31.2516	Class B			
	50.8949	Class A	*	*	
Map V	12.1533	Class C			
	10.4170	Class B			
	29.6449	Class A	*	*	

(*) denotes pairs of groups significantly different at the 0.050 level.

To determine the effects of instructional strategies on students' conceptual change patterns regarding general public notions and specific genetic concepts, the responses of individual student to the pre-instructional and the post-instructional tasks are compared and summarized in Figure 25.

On average 20.28% of Class A shifted to more accepted scientific viewpoints in relation to general public notions and 16.18% in relation to specific genetic concepts. Only 14.95% of Class B and 16.62% of Class C improved their explanations of tasks related to general public notions, and 6.44% of Class B and 6.78% of Class C in relation to specific genetic concepts.

Quite a number of students consistently used alternative conceptions in response to the tasks. 8.86% of Class A and 10.80% of Class B demonstrated this pattern in response to tasks related to general public notions, and 9.78% and 11.30% of Class A and B, respectively, in response to tasks related to specific genetics concepts. Only 5.68% and 3.84% of Class C used the same conceptions as they did prior to instruction in response to tasks related to general public notions and specific genetic concepts respectively.

a = Consistent use of accepted conceptions
b = Consistent use of alternative conceptions
c = Change from alternative to accepted conceptions
d = Change from alternative to another alternative conceptions
e = Change from accepted to alternative conceptions
f = No responses were given before and/or after instruction

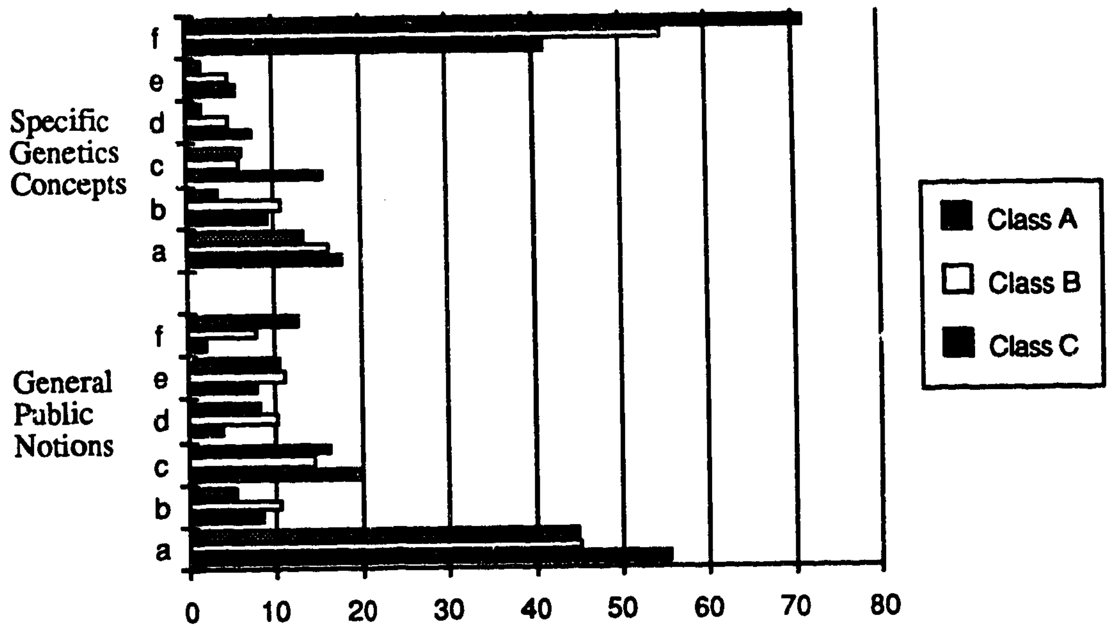


Figure 25. Comparison of mean of changes in individual responses to tasks given before and after instruction.

It was quite disappointing that 8.29%, 11.38%, and 10.83% of students from Class A, B, and C, respectively made responses which indicated a regression from accepted ideas toward alternative conceptions regarding general public notions, and 6.19%, 5.20%, and 2.20% of Class C, respectively, in regard to specific genetic concepts.

There were also changes from one alternative conception to another alternative one across the three groups. This pattern of change was illustrated by 4.30% of Class

A, 10.45% of Class B, and 8.53% of Class C in relation to general public notions, and 7.87%, 5.25%, and 2.30% of Class A, B, and C, respectively, in relation to specific genetic concepts.

Although the percentages of students from current approach classes (Class B and C) who demonstrated disadvantaged patterns of changes were lower than the conceptual change group, especially in relation to tasks probing specific genetic concepts, it does not mean that the conceptual change strategies resulted in a negative change in students conceptual knowledge. When one looked closer at those patterns of change, one observed that much higher percentages of students from Class B and C did not provide any responses to tasks given before and/or after instruction (41.67% of Class A, 55.18% of Class B, and 71.45% of Class C). It may be worthwhile to give more details, i.e. that there were 26.19%, 36.60%, and 49.40% of Class A, B, and C, respectively, who did not give any responses to tasks probing the understanding of concepts both before and after instruction, or did not respond on the pre-test but suggested alternative conceptions on post-test. The results imply that students of the current approach groups made less gains in conceptual knowledge.

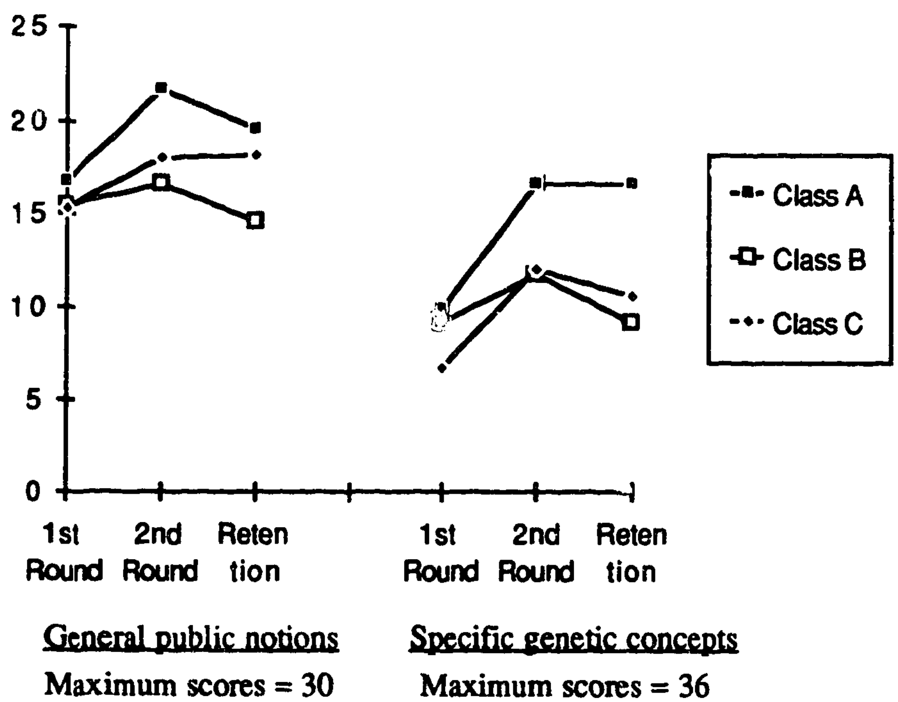


Figure 26. Comparison of mean scores of general public notions and specific genetic concepts.

The mean scores of general public notions and specific genetic concepts on first-, second-round, and retention tests are shown in Figure 26.

Over all, students from Class A performed better on the second-round assessment on general public notions but dropped slightly on the retention assessment. Students from Class B had the same pattern as of Class A. Surprisingly, students of Class C tended to slightly improved as they undertook the last two assessments.

Students from Class A scored higher on the second-round assessment and retained their score level on the retention test in response to specific genetic concepts. Students from Class B and Class C had the same pattern. They scored higher on the second-round assessment and dropped slightly on the retention assessment.

Series of ANOVA's were done for the first-round through the third-round assessment by class. The results (Table 13a and b) indicate that no two groups were significantly different at the 0.05 level on the first-round test on general public notions. However, on the second-round assessment, there were significant differences in the mean scores between Class A and Class B, and Class A and Class C, but no differences between Class B and Class C. The results further indicate that on the retention assessment (the third-round), there were significant differences between Class A and Class B, and Class B and Class C, but no differences between Class A and Class C.

Regarding specific genetic concepts, the statistical tests indicate that on the first-round assessment, there were significant differences between each of the two groups except between Class A and Class B. These results show that the comparability of the groups can not be established on this basis. However, the results illustrate different trends in students' development of conceptual understandings. Class A students developed more accurate understandings and were more able to retain these understandings than other classes.

Table 13a. Results of series of one-way ANOVA's of mean scores of general public notions and specific genetic concepts by group.

Source	D.F	SS	MS	F-Ratio	P- value
Gen. I (1st round)					
Between groups	2	45.3181	22.6591	1.3903	.2533
Within Groups	112	1825.3427	16.2977		
Total	114	1870.6609			
Gen. II (2nd round)					
Between groups	2	509,5292	254.7646	18.3376	.0000
Within Groups	111	1542.1287	13.8931		
Total	113	2051.6579			
Gen. III (Retention)					
Between groups	2	378.9331	189.4665	11.8450	.0000
Within Groups	95	1519.5669	15.9954		
Total	97	1898.5000			
Specific. I (1st round)					
Between groups	2	164.8627	82.4313	7.1929	.0012
Within Groups	112	1283.5373	11.4602		
Total	114	1448.4000			
Specific. II (2nd round)					
Between groups	2	548.653262	274.3262	12.0757	.0000
Within Groups	112	2521.6021	22.7171		
Total	114	3070.2544			
Specific. III (Retention)					
Between groups	2	975.0344	487.5172	22.3076	.0000
Within Groups	95	2076.1595	21.8543		
Total	97	3051.1939			

Table 13b. Significant differences between groups on mean scores of general public notions and specific genetic concepts.

Variable	Mean	Group	Class C	Class B	Class A
General I	15.349	Class C			
	15.351	Class B			
	16.714	Class A			
General II	17.952	Class C			
	16.568	Class B			
	21.714	Class A	*	*	
General III	18.139	Class C			
	14.593	Class B	*		
	19.486	Class A		*	
Specific I	6.6512	Class C			
	9.1622	Class B	*		
	9.0857	Class A	*		
Specific II	11.9524	Class C			
	11.7297	Class B			
	16.6000	Class A	*	*	
Specific III	10.5833	Class C			
	9.2222	Class B			
	16.4857	Class A	*	*	

(*) denotes pairs of groups significantly different at the 0.050 level.

The total mean scores on first-, second-round, and retention tests are shown in Figure 27.

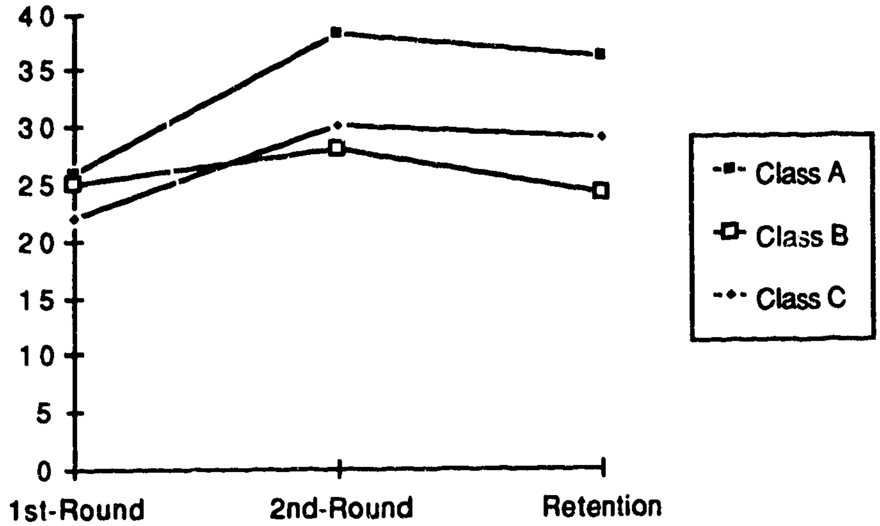


Figure 27. Comparison of total mean scores across three rounds of assessment.

Tables 14a and b show the results of ANOVA's of total mean scores.

Table 14a. Results of series of one-way ANOVA's of total mean scores (general public notions + specific genetic concepts) by group.

Source	D.F	SS	MS	F-Ratio	P value
Total I					
Between groups	2	295.0176	147.5088	4.4762	.0135
Within Groups	112	3690.8432	32.9540		
Total	114	3985.8609			
Total II					
Between groups	2	2086.9680	1043.4840	23.490	.0000
Within Groups	111	4930.8916	44.4224		
Total	113	7017.8596			
Total III					
Between groups	2	2339.5680	1169.7845	25.5220	.0000
Within Groups	95	4354.2677	45.8344		
Total	97	6693.8367			

Table 14b. Significant differences between groups on total mean scores (general public notions + specific genetic concepts).

Variable	Mean	Group	Class C	Class B	Class A
Total I	22.0000	Class C			
	24.5135	Class B			
	25.8000	Class A	*		
Total II	29.9048	Class C			
	28.2973	Class B			
	38.3143	Class A	*	*	
Total III	28.7222	Class C			
	23.8148	Class B	*		
	35.9714	Class A	*	*	

(*) denotes pairs of groups significantly different at the 0.050 level.

Similarly, the series of ANOVA's done by class (Table 14a and b) indicate that although there was no significant difference between the total mean scores between Class A and Class B on the first-round assessment, there were found to be different between the two groups immediately after instruction and the retention period. In contrast, there were significant differences between Class A and Class C throughout the three rounds of assessments.

The results can be interpreted that regarding general public notions and specific genetic concepts under study, the conceptual change teaching approach was somewhat more effective than the current teaching approaches.

The comparative results of the total mean scores of written tasks (excluding concept maps) given in five sessions for the three groups of students are shown in Figure 28.

Students from Class A scored lowest on the first session, then surpassed other classes on all following sessions. Students from Class B scored second on the first session through the third session but followed Class C on the post and retention tests. Students from Class C scored highest on the first sessions, then dropped to the lowest rank on the second and the third sessions. They later surpassed Class B on post and retention tests.

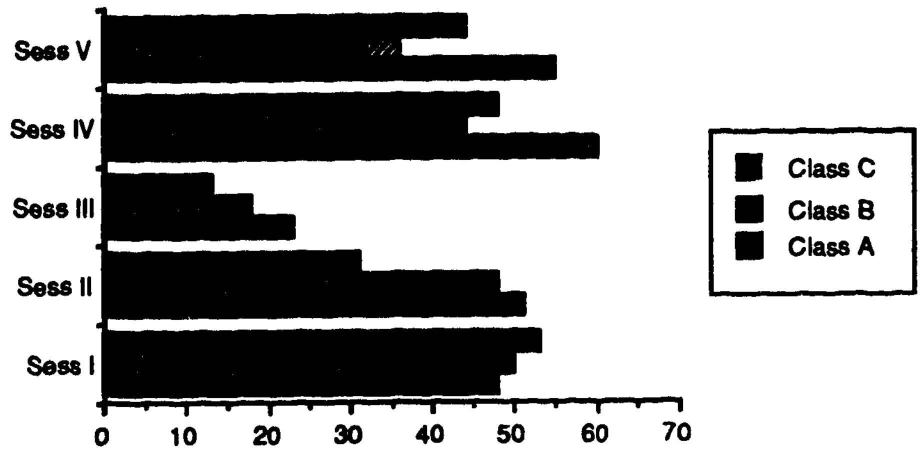


Figure 28. Comparison of mean scores across five sessions (in percent).

Multiple analysis of variance were done for the first session through retention test by class (See Appendix 7). The MANOVA's tests indicate that although there were some differences between groups of students at the very beginning, these differences were not significant. However, as the students progressed through the unit instruction, there tended to be more discrepancies in students' understanding of the concepts (except for Session III). The MANOVA's tests also indicate that on both post and retention tests, there were significant differences between students of Class A and Class B, and Class A and Class C, but there was not significant difference between Class B and Class C.

Therefore, it can be concluded that the cooperatively-designed teaching approach was more effective than the two current self-developed teaching approaches in improving students' understanding toward valid scientific concepts.

Chapter V

Interpretations, Discussion, and Suggestions for Further Study

Introduction

In this final chapter, a summary of the purpose and design of the study is presented. The results presented in Chapter IV are interpreted and discussed. Finally some recommendations for the classroom teaching of heredity and further research are suggested.

Overview of the Study

The purpose of this study was to identify students' alternative conceptions about genetics and to compare the effectiveness of two instructional approaches, identified as current self-developed teaching approaches and a cooperatively-designed teaching approach, in bringing about a valid understanding of selected concepts in the Mathayom Five (Grade eleven) students. More specifically, this study aimed to answer the following questions:

1. What are the common alternative conceptions that grade 11 Thai students hold about heredity prior to and following two instructional treatments?

2. How can knowledge of students' alternative conceptions influence the way in which the teacher plans and presents the lessons?

3. How effective are the designed lessons which are aimed at correcting students' alternative conceptions?

The sample for this study consisted of 115 students in Mathayom 5 (Grade eleven) biology classes of three upper secondary schools in Khon Kaen, Thailand, in the academic year of 1990-1991. Two teachers used their current self-developed teaching approaches and another teacher implemented a cooperatively-designed teaching approach aimed at changing students' alternative conceptions for the heredity unit over a period of two to four weeks. Throughout the period of the study, the written tasks (Thai versions) relating to the concepts associated with the study of heredity were given periodically. The pre- and post- instruction interviews were conducted with six selected students from each class to supplement data collected from the written tasks. Classroom observations, lesson plans reviews, and teachers' dialogic interviews were performed to provide further information of classroom implementation.

Interpretations of the results

The analysis of the data obtained in this study resulted in the following interpretations and recommendations.

Students' Preconceptions

Information obtained from the students' written tasks and interviews revealed that the students already had developed their own ideas about inheritance prior to entering formal instruction. The beliefs were acquired either through an interaction with environment or influenced by language and culture. They sometimes used previously acquired formal knowledge in an intuitive way. This appeared to be similar to that described by Dreyfus *et al.*, 1990.

The data obtained indicated that, before instruction, about half of the 16-17 year old students in this study did not mention genetics when responding to the questions probing about the difference between acquired characteristics and hereditary inherited traits (Question # 2.1, 2.2, 6.1, and 6.2). Some students still believed that some environmentally produced characteristics could be passed on to the next generation. As well, some students believed that genetic factors had no effect on the development of athletic skills.

It was also found that students believed the passage of time influenced the transmission of phenotypic change. They adopted Lamarckianism where the use or failure to use certain organs or abilities or an adaptation of individuals were seen as processes of evolution. This result supplements the finding of Bishop and Anderson (1990) who investigated college students' conceptions of natural selection and its role in evolution.

Many students demonstrated alternative conceptions in responding to the questions related to the possibilities of the inheritance of fur color in animals and height in humans (Question # 3.1, 8.1, and 8.2). Their explanations included their everyday experience, their beliefs in parenthood, and alternative genetic principle interpretation.

They seemed to be rigid in their thinking without awareness of many variables which may contribute to making predictions.

The highest percentage of students did not understand the equality of genetic contribution by each parent during sexual reproduction (Question # 3.2). Their alternative conceptions may be rooted from the confusion of the meanings of the word "dominant" in a hereditary context. Students viewed the word as its everyday usage meaning; the controlling or influential aspect of one person in relation to another. Furthermore, the instruction did not relate the term dominant or recessive to homozygous and heterozygous. Consequently, students perceived that the parent who has a dominant trait would contribute more.

The last concepts related to common knowledge investigated in this study were the likeness and differentiation between siblings (Question # 4.1 and 4.2). Students had some ideas why siblings were similar but they had difficulties in explaining the causes for the differences. These findings supported those of Engel Clough and Wood-Robinson (1985) and Dreyfus *et al.* (1990) where the ideas about similar/different genetic units, equal/unequal distribution of genes from parents, and timing of fertilization and nourishment were mentioned. Most students could not give comprehensive, scientific explanations. This was not surprising because daily experiences show nothing about the mechanism of transmission (Dreyfus *et al.*, 1990).

An analysis of variance indicates that there was no significant difference between the three participating classes at the 0.05 level on the first-round implementation of these general public notion tests. The results assure that prior to instruction each group of students had similar varieties of conceptions relating to common knowledge about genetics. Therefore, it is possible to discuss the issue of what contributes to differences in students' conceptions after instruction.

For more sophisticated concepts, students' ideas were examined through the meaning of terminology (Questions # 5.1, 5.2, 5.3, 10.1, 10.2, and 10.3) and through problem-solving on monohybrid cross (Question # 7.1 and 7.2), dihybrid cross (Questions # 9.1 and 9.2), and multiple alleles (Questions # 11.1 and 11.2). The results indicate that, before being taught at school, many students had little or no knowledge about these sophisticated abstract concepts. The findings are supported by Dreyfus *et al.* (1990) who investigated high school students' understandings about the function of cell membrane. However, it was also found that some students had developed the knowledge either through their independent study at private intensive tuition schools or their attempts in applying previous formal knowledge to an explanation.

The most common alternative conception about problem-solving found in the study was that gametes contained both alleles of the pair. This conception was found in students regardless of whether or not they were able to obtain the correct solutions to the problem. This suggests that students used memorized patterns of solving problems, without accurate conceptual understanding of genetics.

Students had difficulties in assigning proper symbols to represent alleles for a trait. They also lacked accurate understanding of the segregation and recombination of alleles during reproduction. After all, most of the students could not present a diagrammatic representation of gene segregation and recombination to support their answers.

The results further indicate that the students had little or no knowledge about the term "allele" and about the function of genes in the transmission of traits. The teacher may be part of the reason if he or she is not clear about the concepts him/herself. Also, these concepts may be too highly sophisticated or abstract, and beyond the level of the students' cognitive abilities.

In summary students alternative conceptions were due to the lack of accurate understanding of abstract concepts of meiosis, segregation, and assortment, including the concepts associated with the relationships among chromosomes, genes, and alleles. They failed to realize that there was a relationship between meiosis and problem-solving in genetics. Their understanding of meiosis was also too vague to allow them to apply it to new situations. These results supplement the findings of Stewart (1982a, b), Tolman (1982), Cho *et al.* (1985), and Stewart & Dale (1989).

An analysis of variance indicates that there was a significant difference in the mean scores on the first-round implementation of the specific genetic concept tests between students in Class A and Class C and students in Class B and Class C. However, there was no significant difference between Class A and Class B. In spite of different bases on developed conceptions about these specific genetic concepts among the three groups, the results may also reflect many controllable and uncontrollable factors in the research. For example, the fact that the assessments were administered over several sessions prior to and during instruction may contribute to the differences of total average scores among groups. The repetition of answering "unknown concepts" every week may effect the intention of providing the best response. The high percentage of no responses during the third session suggests this to be the case. Teacher's expectations, students' attitudes and their learning habits, and classroom atmosphere were all factors that may contribute to differences in the results.

Students' alternative conceptions

Like many other research studies, this study found that there were some improvements in the students' conceptions after instruction. However, alternative conceptions still persisted for many students in all three groups.

In addition to those alternative conceptions which had existed prior to instruction, many students formed new alternative conceptions as they tried to assimilate newly learned formal ideas to their existing conceptions. To illustrate this, they knew that cutting tails had no effect on the genetic make-up of an animal, but since they were taught that there were two alleles responsible for a trait, they then interpreted that there must be an allele for tailness and another allele for taillessness, which control the existence of an animal's tail. Consequently, they suggested that there is a possibility to have some tailless animals if the parents happened to be hybrid.

Students often used their newly learned formal knowledge in an intuitive way. As they learned more about abstract concepts of genetics, their interpretation seemed to differ from what the teacher had expected. As a result, there was a variation of responses after instruction as the students answered in more detail. In other cases, socially transmitted ideas may have influenced the construction and reconstruction of knowledge. An example of such "folk knowledge" is that the physical attributes of the mother play an important role in the health of a baby in the womb. Consequently, many students conceived that children of an athlete would be born with a "better" body structure.

There was also confusion on the concepts of the crossing-over of genes on chromosomes, Mendelian's principles of inheritance, variation, incomplete dominance, the processes of meiosis, and specific terms. Such confusion led to the development of ideas which did not conform with the thinking of the scientific community.

Comparison to the results of previous studies

This study's findings are supported by the works of Kargbo *et al.* (1980) and Engel Clough and Wood-Robinson (1985), particularly with reference to the concepts of mechanisms of inheritance. Although the subjects of the present studies were older than those of such studies, the results still repeated the common claim that students held several alternative conceptions both before and after instruction. Students were often confused between acquired changes within an individual's lifetime and long-term inherited changes within populations. They believed that the father and the mother contribute unequally to the offspring. An important origin of this idea relates to the conception of the term "dominant" in everyday use; the controlling or influential aspect of one person in relation to another. Some other alternative ideas may have resulted from difficulties in understanding the processes of meiosis and its relation to inherited transmission. Therefore, the students provided explanations which differed from scientific ideas concerning the variations among siblings. Another similar finding was that the blending of characteristics resulted from the mixing of genes.

New alternative conceptions which have not been identified in the previous studies by Kargbo *et al.* (1980), and Engel Clough and Wood-Robinson (1985), can be stated as the follows:

(a) there is no distinctive trait in animals, therefore, most traits are continuous or appear in intermediate forms,

(b) a specific allele is expressed unequally between different sexes,

(c) the genes for height are sex-linked since men are usually taller than women,

(d) athletic skills are not affected by genetic factors,

(e) children of athletes would be born with "better" body structures,

(f) different orders of genes and chromosomes contribute to differences between siblings

(g) the crossing-over of genes on chromosomes during fertilization results in variation within a family,

(h) the genes which are bound together in different sex cells do not control the same trait,

(i) probabilistic ratio determines the order of phenotypic expression of the offspring, and

(j) mutant genes are recessive.

Children of younger ages form their ideas from sensory experience and everyday communication (Engel Clough *et al.*, 1987) but children of older age appear to acquire more ideas through formal instruction. As a result, the taught ideas which were applied to the task situations used in the study may contribute to the differences in the findings.

For the concepts about Mendelian genetics, the findings complement the information already reported by Longden (1982), Stewart (1982a, b), Tolman (1982), Hackling and Treagust (1984), Thomson and Stewart (1985), Browning and Lehman (1988), Stewart and Dale (1989), and Brown (1990). Students demonstrated a lack of the valid concepts which were necessary for an understanding of Mendelian Genetics. They failed to understand the concepts about chromosomes, genes, meiosis, fertilization, probability in inheritance, and the meaning of terminology. Although the students could get correct solutions by solving problems through an algorithm or a Punnett square model, it was not necessary that they understood the mechanisms of inheritance. Students were more likely to use memorized patterns of response in approaching the problem-solving questions (Smith and Good, 1984). Evidence for this approach to solving problems was given through their inability to construct a diagram of genes and chromosomes to support solutions. During the interview session, some students from Class A but none from either Class B or C could provide a valid diagram. Interestingly, the concepts about how genes are located on a chromosome varied considerably. Students appeared at first to understand where the genes were located but it subsequently became clear through the interviews that they did not understand how this took place. Their alternative conceptions were: both alleles of a pair locate on the same chromosome, genes are bound together at the centromere, genes are packed in a chromosome, and genes stick on the surface of a chromosome. The results of this and other studies indicate a need for the teacher to be aware of alternative interpretations that occur and to take steps to revise them.

Promoting conceptual change

An emphasis on promoting conceptual change focused on the active participation of students in a process of reshaping and restructuring their knowledge. The role of the teacher has to shift from a didactic presenter of knowledge to a facilitator who leads the students to be responsible for exploring and modifying or replacing their existing knowledge by new valid ideas.

This concern about the changing role of teachers leads to another question: How can knowledge of students' alternative conceptions influence the way in which the teacher plans and presents the lessons?

An analysis of classroom observation and dialogic interviews with the teachers indicated that Teacher B and C were generally unaware of students' alternative conceptions. They were frequently not sensitive and willing to listen to the ideas children bring with them to the lessons. Both teachers rarely provided opportunity for students to explore or debate their viewpoints. Moreover, when alternative conceptions were explicit, the teachers usually ignored them or even rejected them without any explanation. Lesson presentation extensively followed the textbook and teachers' guide provided by the Institute for the Promotion of Teaching Science and Technology (IPST). The aim of instruction was to cover the curriculum authorized by the Ministry of Education. The teachers felt that they could not take time for many discussions.

In contrast, Teacher A who implemented the conceptual change teaching strategies demonstrated her awareness of students' conceptions. She often provided opportunities for students to identify and justify their ideas during discussion. She seldom used her authority in evaluating students' opinions but rather she challenged them to compare and contrast alternative views and helped them to reconstruct their knowledge. Her role shifted from a knowledge transmitter to a facilitator for conceptual change.

It can be concluded that knowledge of students' alternative conceptions may contribute to a teacher's awareness of students' existing knowledge but it might be too soon to jump to the conclusion that it also contributes to a shift in planning and presenting the lessons since the teacher and the researcher cooperatively put an effort into preparing instructional materials and planning the lessons. When presenting the lessons, it was observed that the teacher tried to help students to achieve alternative ways of thinking by creating discrepant events and letting them compare and contrast the ideas through discussion but very often she went on to the traditional explanatory teaching method. However, the teacher appeared to be more careful and sensitive to students' responses.

In the design of this study, a retention test was conducted four months after the unit instruction. An analysis of changes between the pre, post, and retention test indicated that Teacher A was partially successful in implementing conceptual change strategies. Nevertheless, there were some difficulties which have been observed during the implementation. The difficulties were compatible with those reported by Dreyfus *et al.* (1990) and Neale *et al.* (1990). First of all, a shift from the old ways of "successful teaching" (as a knowledge transmitter) seemed to be strange and difficult to accept, especially for those students of the Thai culture, where people have a high sense of respect for seniority and the teacher still possesses this traditional authority in administrating and disciplining classroom activities. The teacher should value the necessity of changing students' alternative conceptions otherwise he or she would fall into a trap of community expectation which cares mainly about academic achievement. Thai universities prefer to use that achievement of detailed aspects of knowledge as the basis for the entrance examination on which selection is determined.

The new approach also requires a thorough understanding of subject matter so that the teacher can be confident and competent in identifying and responding to students' alternative conceptions. In addition to the ability to explore existing ideas of students, a more difficult job for the teacher is to be able to challenge those conceptions by providing a context in which both the conflict and the solution are meaningful to the students. Teacher A was sometimes uncertain as to whether the students' ideas were valid or not. She sometimes even held alternative conceptions herself. To illustrate, she believed that mutant genes are recessive and a crossing-over of genes on chromosomes is a major source of variations among siblings. She misused the term allele as two contrasting genes which control a trait; therefore she explained that a gene for round peas was alleled to a gene for wrinkled peas. This problem also occurred in the other two classes. The findings that teachers sometimes possess alternative conceptions themselves were also reported by Ameh and Gunstone (1985), and Berg and Brouwer (1991). It was not surprising that some alternative conceptions were held by students as a result of the teacher's own misinterpretations.

Time constraint is another difficulty with which a teacher is confronted. The new approach needs more time for students to discuss and debate, and a teacher sometimes feels that she could not take the time. The reason often given was that she might not be able to complete the content in the curriculum. Therefore, Teacher A cut short a process from time to time or opted for the current dissemination approach to teaching over the conceptual change approach.

Lastly is the factor of the students themselves. Their attitudes to learning and the subject may result in their willingness or unwillingness to participate in the activities. As one student said, "I am going to be an engineer, I don't need to be that good in a biology course. I just expect to pass and get the credits to fulfill the requirement." Also, as mentioned before, Thai students have a high sense of respect for seniority, as well as a belief that "more words won't help matters," they seldom criticize or argue against someone else's ideas. Such students preferred to be told about the content rather than actively participating in the learning process. Those students' passive interest in discussion often discouraged the teacher's intention to implement conceptual change teaching strategies.

In conclusion, although the conceptual change teaching approach may hold greater potential in its ability to correct conceptual knowledge, it may be too optimistic to recommend this teaching model for classroom implementation. More preparation is needed to be done including teacher training, instructional materials, and a teachers' guide. It is possibly more suitable to use the model as a means to develop a curriculum appropriate for individual students.

Comparison to the results of other studies

The present study attempts to draw comparisons between a conceptual change approach and a current textbook- and teachers' guide-based approach. An emphasis on conceptual change strategies appears to lead to an improved ability by the students to identify the network of interrelationships among concepts, as indicated by comparisons between groups to the average scores in the post and retention tests.

It is evident that students from Class A (the treatment group) were more consistent in reasonable levels of meaningful learning as new concepts were introduced throughout the instruction, as shown in Figure 24, Chapter IV. Furthermore, a change from the post to the retention test indicated less memory decay in the treatment group. These changes were sufficient to conclude that the approach was more effective in developing students' understandings of the relationships betwee.. concepts related to genetics, although the average score of the treatment group was only 50.89%.

Through a more in-depth analysis, student patterns of concept mapping found by Novak and Musonda (1991) were also observed in this study. Although these researchers conducted a study with American students on the concepts related to the nature of matter, there was a conformity in the results of both studies. They used audio-tutorial lessons aimed at teaching ba..c science concepts to children in grades one and two. One group of the sample received tutorial lessons but the other did not. These children were interviewed periodically to determine changes in their conceptual understanding from grade one through twelve. From interview transc..pts, c...c... maps were constructed by research assistants. An analysis of data indic... d that the treatment group demonstrated more accurate conceptual understandings a... ... ...rnative conceptions than the control group students. However, their conc... ...apping showed wide variations in knowledge among th... ...uals and some students retained their reasonable levels of meaningful learning ... ...rs moved to patterns of rote-mode learning, regardless of instructional approac...

The results of this study and others would imply that we can no longer assume that students will develop the desirable network of relationships between concepts in accordance with gain in valid cognitive knowledge. The teacher may rather make specific attempts to address how new concepts relate to and how they are similar or different from, other already learned ...s.

For the development of ...nceptual understanding, some differences of changes and stability of thinking ... ...re ...oserved when compared to the study done by Engel Clough *et al.* (1987). Where no attempts were made to intervene in the learning process, they found that more than half of the students between ages 12-14 and 14-16 used the same alternative conceptions in response to questions concerning the inheritance of acquired characteristics. This study expanded the results that most students, ages 16-17, regardless of instructional strategies, consistently used appropriate conceptions. However, the number of students consistently using alternative conceptions increased when asked what they expected to happen in the far future regarding the inheritance of envi...nmentally produced characteristics. More than 10% of each class consistently used alternative conceptions that acquired running skill could be passed on to the offspring after a period of time. Even worse, about 10% or more of each class changed from accepted to alternative conceptions that genetic factors did not play any role in human skills.

The results of this study also support Bishop and Anderson' s (1990) conclusion that regardless of the intervention, some students continue to believe that evolution is gradual change in the traits themselves rather than a change in the proportion of individuals in a population.

While the studies of Kargbo *et al.* (1980) and Engel Clough and Wood-Robinson (1985) did not address patterns in the development of thinking in individuals, this study observed that more than one-fourth of the students in each group consistently used the same alternative conceptions in responding to the question " Which one of the parents do you think will have greater influence on the characteristics of the offspring?" They retained their belief that the parent who had the dominant trait would have greater influence. This may result from the common meaning of the word "dominant." Usually people say, "My mom has a stronger will than dad. She must be dominant. That's why I have her eyes." Therefore, it is not surprising that more than 10% of each group changed from their other alternative conceptions and some students even changed from their initially valid conceptions to this alternative conception.

The study further found that as the students learned more about genetic principles, about one-fifth or more of the students from the teacher's own style teaching approach (a textbook- and teachers' guide-based approach) groups appeared to be even more confused as they opted not to respond to the questions asking why siblings usually look more alike but also have distinguish characteristics.

None of the previous studies address patterns in development of thinking in individuals that resulted from different instructional approaches concerning specific genetic concepts. This study reveals that very few students, regardless of instructional approach, had some appropriate ideas of how genes function in the transmission process. The highest percentage of students (except Class C where students opted not to give any responses to the question either before or after instruction) consistently used the alternative conception that a gamete carries both alleles of the pairs found in parent's body cells. Also, a high number of students, regardless of instructional approach, consistently could not assign appropriate allele symbols to the multiple alleles problems. The study further found that most students, especially those from the current approach classes, who had no ideas concerning the concepts related to dihybrid cross and multiple alleles prior to instruction, gained little knowledge during instruction so that they opted not to respond to the questions after instruction.

Although beliefs in these alternative conceptions by all groups remained stable regardless of instructional strategies, the students in the conceptual change teaching approach group appear to hold less alternative conceptions than did members of the other classes. They, too, demonstrated development of more accurate conceptual understandings while the students in the current teaching approach gained less as evident by a high percentage of non-responses to the complex questions.

Summary and Discussion

As discussed earlier, the cooperatively-designed teaching strategies were somewhat successful in bringing about conceptual changes as indicated by changes of scores the students achieved in the pre, post, and retention tests.

However, it was also found that in spite of learning the concepts related to inheritance during previous and present classes, alternative conceptions continued to persist in the eleventh grade students who participated in the study. It was found that Lamarckianism had an influence on students' beliefs about changes in hereditary traits in a population and the beliefs appeared to be supported by a local media. In particular, a cartoon produced in a magazine and presented on television, asserts these perspectives. Another source of these beliefs may be misinterpretations of the history of evolutionary theories presented in science books or in science units in previous grades. Teachers may, therefore, need to be more careful in presenting the history of science because once alternative conceptions occur, they are difficult to alter (Osborne *et al.*, 1983). Instead of introducing what knowledge has been discovered by whom, the lesson may have to be presented in a manner that shows why the competing paradigms occurred and how the older, less accurate paradigms become replaced. In the case of Class A, part of the reason why some students still retained their beliefs may be that the teacher provided some alternative conceptions. While presenting the lesson on "the heredity and environment," she indicated that a baby born from an athletic mother would be healthy and its body structure would also be "better" than what it normally would be as a result of inheriting strong muscles from the mother who trained hard to be a good runner. The finding that teachers sometimes possess alternative conceptions themselves is also reported by Ameh and Gunstone (1985) and Berg and Brouwer (1991).

It was also found that students failed to understand everyday phenomena in the context of genetics principles as was evident by their responses to the questions which related to variations within a family and the equality of genetic contribution by each parent in sexual reproduction. These alternative conceptions might not be retained if the students had adequate understanding of the separation of chromosomes and gene pairs during meiosis, and the subsequent reformation of gene pairs during fertilization.

Although the patterns of instruction during the conceptual change teaching approach frequently emphasized the related meiosis concepts throughout the unit on inheritance, some students still retained the same conceptions after instruction as they did prior to the study. Part of the reason may be that the memorization of isolated pieces of information the students achieved during instruction of the reproduction unit had been so deeply rooted that they provided the basis for the formation of alternative conceptions. Because intuitive notions about one concept may lead to alternative conceptions about other concepts (Westbrook and Marek, 1992), the emphasis on the relationships between specific concepts alone during the unit of inheritance is not sufficient to alter conceptions. The implication for teachers and curriculum developers may be that careful instruction should be designed to develop valid understanding of meiosis and that it be taught in the context of reproduction and inheritance.

Another prevalent alternative conception found in this study is a failure to understand the role played by chance in the process of inheritance. This conception may be rooted in a misinterpretation of Mendel's experiments. Usually, the lessons on these experiments concluded that all the offspring produced in the F_1 generation by a parent of dominant trait and a parent of recessive trait will definitely have the dominant trait. Students often appeared to be unaware that a dominant trait could result from two heterozygous alleles. Also, students believed that three out of four children produced by hybrid parents will definitely have the dominant trait. Again, if instruction emphasizes a genes-on-chromosomes model for illustrating a process of problem solving and the students have adequate basic understanding of meiosis, such students may be capable of understanding the phenomenon of probability in inheritance.

Compatible with other previous studies, one of the most significant findings in this study is that students preferred to use memorization of patterns of algorithms in solving genetics problems. All students from the teacher-designed teaching approach groups did not illustrate a genes-on-chromosomes model to support their solutions throughout the study even though they could produce the correct answers. During the interview session, these students could not construct the appropriate model. Some students from the conceptual change teaching approach class could provide the model in the post test and fewer students could do so in the retention test. The results imply that the students were able to solve the problems without an accurate understanding of chromosome and gene movement during meiosis. This conclusion was confirmed by the evidence that many students perceived that gametes carry both genes from the pairs found in parent's body cells. Teachers may need to de-emphasize the algorithm methods but emphasize connecting the processes of meiosis during the solving of problems.

Students could not distinguish between the concepts of gene and allele, and these alternative conceptions led to difficulties in understanding of the concepts about multiple alleles. The difficulties may result from inadequate understandings of the concepts by the teachers themselves and through curriculum developers overlooking the importance of the concept of the allele. The IPST textbook introduces the concept by indicating that,

> ....Genes which are located on the same loci of homologous chromosomes can be said to be alleled. Therefore, T and t are alleled to each other......Some characteristics of living things may be found to be controlled by more than two forms of genes, probably three forms; for example, A, A', A", and we can say that there are three alleles. When they combine in pairs, there will be six possible genotypes: AA, AA', AA", A'A', A'A", A"A." The phenotypes depend on whether genes are dominant or recessive (p. 100).

Moreover, the teachers' guide indicates that:

> Allele is an abbreviation of the word allelomorph which refers to genes which control the same trait. This pair of genes, for example, Aa, AB, or AA', are located on the same loci on the homologous chromosomes. Notice that genes which are alleled are not always the genes that control the dominant and recessive traits. During instruction, do not emphasize the questions about the number of alleles in different forms of genotypes because it is meaningless in genetics. Sometimes, the geneticists themselves use the terms allele and gene interchangeably. Also, it is not preferable to say that a pair of genes which are homozygous, such as AA or aa, are alleled to each other because they are the same form of genes, and do not effect any difference in appearance (p. 94).

As a result, the three teachers in the study including Teacher A used the term "allele" less and used the term "gene" when teaching about multiple alleles. If the topic of multiple alleles is introduced at this level, it is necessary to develop understanding of the concept of allele and its relation to the gene and trait in order to avoid confusion and alternative conceptions which may occur during the problem solving on multiple alleles.

In conclusion, to develop valid conceptions of the phenomenon of inheritance, the underlying concepts necessary for its understanding should be emphasized. Those concepts include the processes which occur during meiosis and fertilization. Teaching strategies alone cannot produce satisfactory effects because success in changing conceptualizations are influenced by many key factors. These factors include classroom situation; teacher's beliefs, expectations, knowledge, and competencies; students' intellectual abilities and learning styles; students' attitude and willingness to struggle for deeper understanding; and, social expectation. Curriculum developers may have to consider these factors before the implementation of these strategies is sugg- sted.

Recommendations and Suggestions fc Further Study

Although the results of this study may not be generalizable due to its design in using a sample of limited size and non-randomized sampling, the findi some implications for science curriculum designers, science educators, and classroom teachers.

1. Despite the growing literature on stu ' alternative conceptions, teachers have not paid much attention to those research re everal attempts should be made to persuade teachers to place significance on them. Meanwhile, appropriate information, curriculum materials, and supplies should also be available to support implementation of the constructivist approach to learning in classrooms.

2. Teachers sometimes possessed alternative conceptions. Such distorted ideas can be disseminated during instruction in the classroom. How can these teachers help students change their beliefs and develop an accurate understanding of science concepts while they themselves have a poor understanding? It is crucial that college science course instructors become aware of these typical alternative conceptions and pay more attention to areas in which science instruction must be sensitive.

3. The results of this and other studies indicate that current science instruction often fails to address or to change alternative conceptions that students bring with them to class, whereas the conceptual change strategies appear to have more positive effects on making conceptual shifts. However, beliefs in certain alternative viewpoints remained stable with individual students. Much work remains to be done in developing and refining teaching strategies which are both effective and fit the realities of schools, before these approaches are introduced into classrooms.

4. Teachers require considerable support in implementing conceptual change teaching strategies. Such support can be developed thorough understanding of science concepts; knowledge about students' likely alternative conceptions; knowledge about how to elicit and challenge those conceptions; knowledge about how to help students become dissatisfied with any existing erroneous ideas; and also, knowledge about ways of responding and explaining concepts in order to help students recognize why certain explanations are considered to be better than others. Therefore, teachers need to have an adequate preparation by experiencing a constructivist teaching model through pre-service or in-service education before taking on a newly introduced teaching approach.

5. Since Thai teachers rely heavily on science textbooks and teachers' guides, it is necessary for the writers to be more careful in presenting any information because textual errors or omissions may constitute "blocks" in later understanding (Cho *et al.*, 1985). Also, information necessary for supporting conceptual change learning should be included in those curriculum materials, otherwise no change could be realized. At the same time, evaluation techniques should pursue more in-depth, rather than rote knowledge.

The findings of this study suggest possibilities of further research as follows:

1. Despite the growing interest in investigating students' conceptions about particular science topics in many countries, a review of literature indicates that Thai researchers pay little attention to this field of research. More studies should be conducted with Thai students on various topics in different grade levels. Since some alternative conceptions are influenced by culture, the findings would be beneficial to curriculum developers to design curriculum materials which are appropriate to the Thai society as well as the knowledge background of Thai students.

2. One purpose of this study was to identify Thai students' alternative conceptions and find out how those ideas changed during instruction of the inheritance unit. The study focused mainly on an analysis of data obtained from written tasks. Nevertheless, it was observed that interviews with a few students were very effective in obtaining rich information about those individual's ideas. Thus, in order to track changes in students' conceptions which result from instruction and identify factors which influence each individual to change the ideas, further research might include an in-depth study with a limited number of students.

3. As discussed earlier, implementation of conceptual change strategies require skills in both cognitive and pedagogical knowledge. Teachers need to have adequate preparation before trying a new approach. Therefore, teacher education programs, either pre-service or in-service, are needed to conduct experimental studies to find what knowledge and skills are needed for conceptual change teaching and how the teaching can be suitably designed for school realities and social conditions.

4. The results of this study and other earlier research indicate that, regardless of instructional approaches, substantial numbers of students held the same beliefs as they did prior to instruction. Part of the reason could be that short-time instruction may not be sufficient to change conceptions because once the alternative conceptions have been developed, they are difficult to alter (Osborne, 1980 and Brumby, 1984). Further research in a long-term study which includes the units of meiosis, inheritance, and evolution is recommended. It is possible that the network of concepts between related topics may contribute to a more effective teaching. Further, an extended period of time may give more opportunities for teachers to elicit greater varieties of alternative conceptions held by individuals for particular items, and develop more appropriate instructional techniques to correct those students' erroneous ideas. Teachers, then, can develop and refine strategies in making their instruction more effective.

5. There is a need for research on teachers' alternative conceptions. Teachers who possess alternative conceptions themselves cannot help students develop accurate understandings of science concepts. If college science and pedagogical course instructors become more aware of the alternative conceptions that their students (future science teachers) might bring to their classes, they may be able to guide those student teachers to more accurate conceptualization. Further, authors of teachers' guide can address the topic of alternative conceptions and suggest ways by which teachers can both correct them and avoid introducing them.

6. In addition to the classroom situation, another key factor which influences success in conceptual change is the students themselves. Only the students can choose to listen to the teacher, determine whether they will accept, reject, or revise ideas, and decide whether they will strive for deeper understanding (Gustafson, 1990). Therefore, it might be useful to explore how conceptual change strategies affect students of different ability levels and why students choose to accept or reject the taught ideas. The findings would be beneficial for developing strategies which are appropriate for students of varying intellectual abilities.

Final Words

This study has attempted to use conceptual change teaching strategies to correct student's alternative conceptions in genetics. Many more questions remain to be investigated so that more effective classroom activities can be designed within a constructive framework. Once constructivist views of learning have been widely implemented, science will be more understandable and applicable for all students.

> "Science is not just a collection of laws, a catalogue of facts, it is a creation of the human mind with its freely invented ideas and concepts."
>
> Einstein and Infeld, 1938 *In* Driver and Erickson, 1983.

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Appendices

Appendix 1

Written tasks given to determine students' alternative conceptions.

Session one

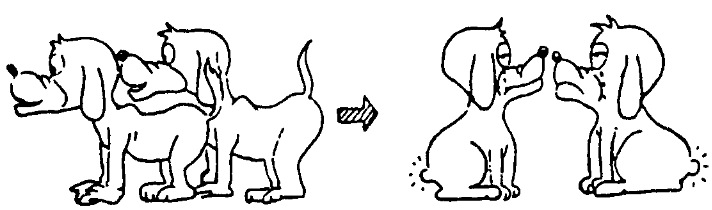
(given prior to instruction)

Concept mapping (Task 1-1). Students were given six concept terms presented in a set of cards, one concept each, and then asked to draw a concept map. The following statements were posed:

Make a concept map using the terms in the cards. You may add any other related terms you feel necessary or helpful in making your map.

chromosome	inheritance
gamete	meiosis
gene	zygote

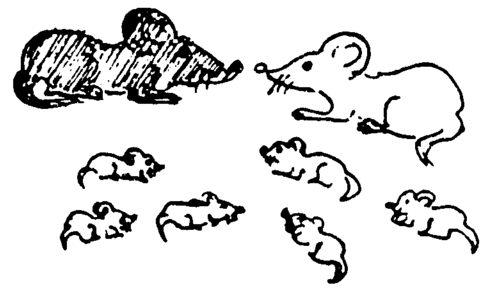
Task two.



2.1 Suppose the tails of two dogs were cut short at a veterinary clinic when they were just two weeks old, if these two dogs later have a puppy, what will be the length of the tail of this puppy? Explain why.

2.2 What would happen if tails were repeatedly cut off over several generations- what kind of the puppies would you end up with? Why?

Task three.



3.1 If a white male mouse and a black female mouse have six offspring, what colors would the offspring be? Why?

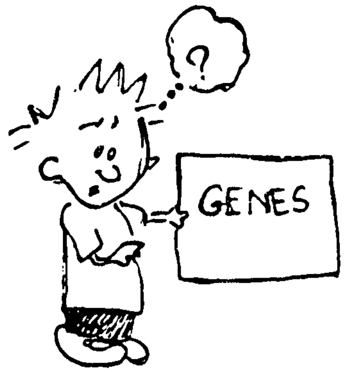
3.2 Which one of the parent mice do you think will have a greater influence on the characteristics of the offspring? Why?

Task four.

4.1 Can you explain why are children in the same family frequently look like one another?

4.2 Why are children in the same family not identical?

Task five.



5.1 What are genes?

5.2 If you know what genes are, where are they located?

5.3 How does a gene function in the transmission of traits?

Session two

(given before the instruction on Mendel's pea experiments and monohybrid cross)

Concept Mapping (Task 1-2). Students were g· ·n nine concept terms (three more concepts are added to the list of concepts given on the first session) presented in a set of cards, one concept each, and then asked to draw a concept map. The following statements were posed :

Make a concept map using the terms in the cards. You may add any other related terms you feel necessary or helpful in making your map.

chromosome	dominant	gamete
gene	inheritance	meiosis
recessive	trait	zygote

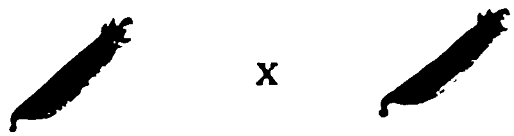
Task six.

A couple had trained hard to become good runners (though they were not particularly proficient naturally).

6.1 Would their children be automatically good runners? Why?

6.2 If the children of this family practiced hard over several generations would you get automatically fast runners in about 200 years? Why?

Task seven.



heterozygous green pod   homozygous green pod

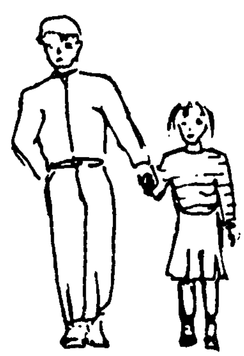
In garden peas, green pod color is dominant to yellow.

7.1 What are the genotypes of each possible gamete produced by a pea plant that is heterozygous green pod? Explain why.

7.2 Give the resulting possible genotypes if a pea plant that is heterozygous is crossed to a pea plant that is homozygous green pod.

Explain how you get the answer by making a diagram representing chromosomes and genes which are involved in the problem.

Task eight.



8.1 If a tall man and a short woman have a child and this child is a boy, how tall will he be in comparison to his parents when he is fully grown? Why?

8.2 If a child is a girl, how tall will she be in comparison to her parents when she is fully grown? Why?

Session three

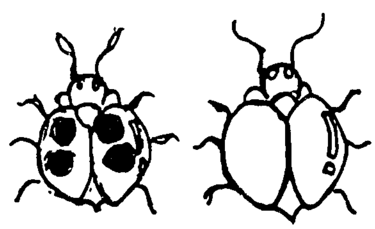
(given before the instruction on dihybrid cross)

Concept mapping (Task 1-3). Students were given twelve concept terms (three more concepts are added to the list of concepts given on the second session) presented in a set of cards, one concept each, and then asked to draw a concept map. The following statements are posed:

Make a concept map using the terms in the cards. You may add any other related terms you feel necessary or helpful in making your map.

allele	chromosome	dominant	gamete
gene	genotype	inheritance	meiosis
phenotype	recessive	trait	zygote

Task seven. (Two questions of task seven were post-tested on session three due to time constraint on Session four tasks.)



In beetles, wings with spots are dominant to wings without spots, and long antennae are dominant to short antennae.

7.1 What are the genotypes of each possible gamete produced by a beetle that has unspotted wings and a beetle that is heterozygous spotted wings? Why?

7.2 What are the possible offspring genotypes of a cross between the beetles on question 7.1?

Explain how you get the solution by making a diagram representing chromosomes and genes which are involved in the problem.

Task nine. From the above situation:

9.1 What are the possible offspring genotypes of a cross between two beetles which have unspotted wings and are heterozygous for antennae?

9.2 Explain how you get the solution on 9.1 by making a diagram representing chromosomes and genes which are involved in the problem.

Task ten. From the above situation, if the wing texture gene and the antenna length gene are on different chromosomes.

10.1 In this problem how many alleles does each gene have?

10.2 How many alleles for each of these traits are present in a diploid cell? Why?

10.3 How many alleles for these traits are present in any gamete cell? Why?

Task eleven.

In the ABO blood group system in humans, the alleles I^A and I^B are incomplete dominant and each is dominant to i.

11.1 If a child is born with blood type A and the mother has type O blood, list the possible genotypes of the father. Explain your choice.

11.2 List the genotypes that the father cannot be. Why?

Session four

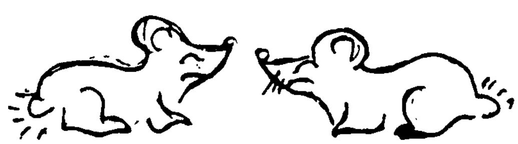
(given immediately after the completion of instruction of the unit)

Concept mapping (Task 1-4). Students were given twelve concept terms (which are identical to concepts given on the third session) presented in a set of cards, one concept each, and then asked to draw a concept map. The following statements are posed:

Make a concept map using the terms in the cards. You may add any other related terms you feel necessary or helpful in making your map.

allele	chromosome	dominant	gamete
gene	genotype	inheritance	meiosis
phenotype	recessive	trait	zygote

Task two.



In an experiment of breeding mice, a scientist would like to see if he could get tailless mice. He cut off the tails of some adult mice and bred them. When these mice with the chopped-off tail are mated,

2.1 What kind of babies would these mice produce? Why?

2.2 Do you think that if he bred the mice with the chopped-off tail again and again he would get tailless mice? Explain your answer.

Task three.

one white and two black males

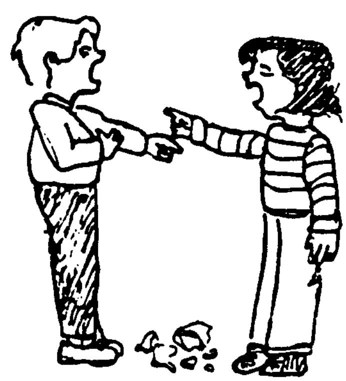
a white female and a white offspring

A student placed a white female guinea pig in a cage with 3 male guinea pigs (one white and two black). Later the female gave birth to a white offspring.

3.1 Which of the males could be the father of the offspring? (if black color is dominant to white) Why?

3.2 Which one of the parent guinea pigs do you think to have a greater influence on the characteristics of the offspring? Why?

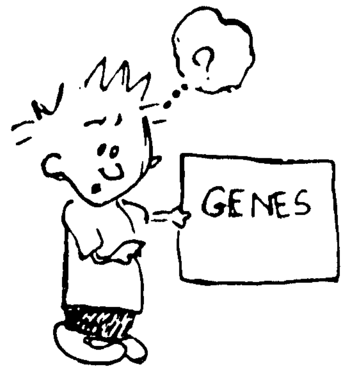
Task four.



4.1 Can you explain why are children in the same family frequently look like one another?

4.2 Why are children in the same family not identical?

Task five.

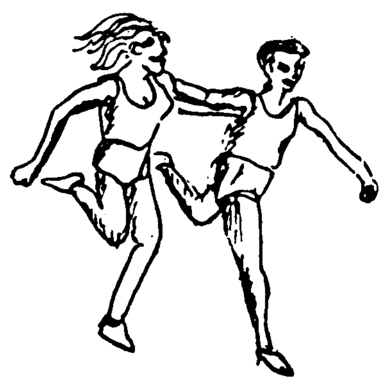


5.1 What are genes?

5.2 If you know what genes are, where are they located?

5.3 How does a gene function in the transmission of traits?

Task six.



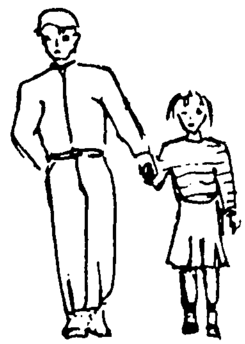
A couple had trained hard to become good runners (though they were not particularly proficient naturally).

6.1 Would their children be automatically good runners? Why?

6.2 If the children of this family practiced hard over several generations would you get automatically fast runners in about 200 years? Why?

__Task seven__. (had been given on the third session tasks.)

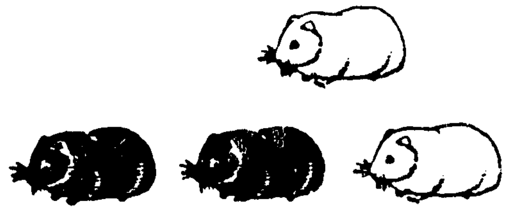
__Task eight__.



8.1 If a tall man and a short woman have a child and this child is a boy, how tall will he be in comparison to his parents when he is fully grown? Why?

8.2 If a child is a girl, how tall will she be in comparison to her parents when she is fully grown? Why?

Task nine.



21 black-rough

6 black-smooth

8 white-rough

2 white-smooth

The gene for black fur is dominant to the gene for white fur and the gene for rough coat is dominant to the gene for smooth coat.

If the results of a different cross of guinea pigs are 21 black-rough, 6 black-smooth, 8 white-rough, . 1 2 white-smooth.

9.1 What are the most probable genotype of the parents? Why?

9.2 Explain how you get the solution by making a diagram representing chromosomes and genes which are involved in the problem.

Tasks ten and eleven.

Suppose that on Mars there exist creatures with three genes controlling hair color. The allele for green hair (H^g) and the allele for purple hair (H^p) are incomplete dominant and each is dominant to the allele for orange hair (H^o). Assume that inheritance of traits on Mars occurs the same way as on Earth.

Task ten.

10.1 In this problem how many alleles does each gene have? What are they?

10.2 How many alleles for this trait are present in a diploid cell? Why?

10.3 How many alleles for this trait are present in any gamete cell? Why?

Task eleven.

If an offspring is born with purple hair and the mother has orange hair,

11.1 List the possible genotypes of the father. Explain your choice.

11.2 List the genotypes that the father cannot be. Explain why.

Session five

(given four months after instruction)

All questions given on this session are identical to those given on session four including task seven which was given on session three.

Appendix 2.A

Scoring guidelines for concept map

Relationships:

One point for each correct relationship between two concepts provided.

Hierarchy:

One point for at least one correct relationship per level.

Branching:

One point for the first branching where two or more concepts are connected to the concept above.

Three points for any subsequent branching where there is an example of two or more concepts connected to a concept above.

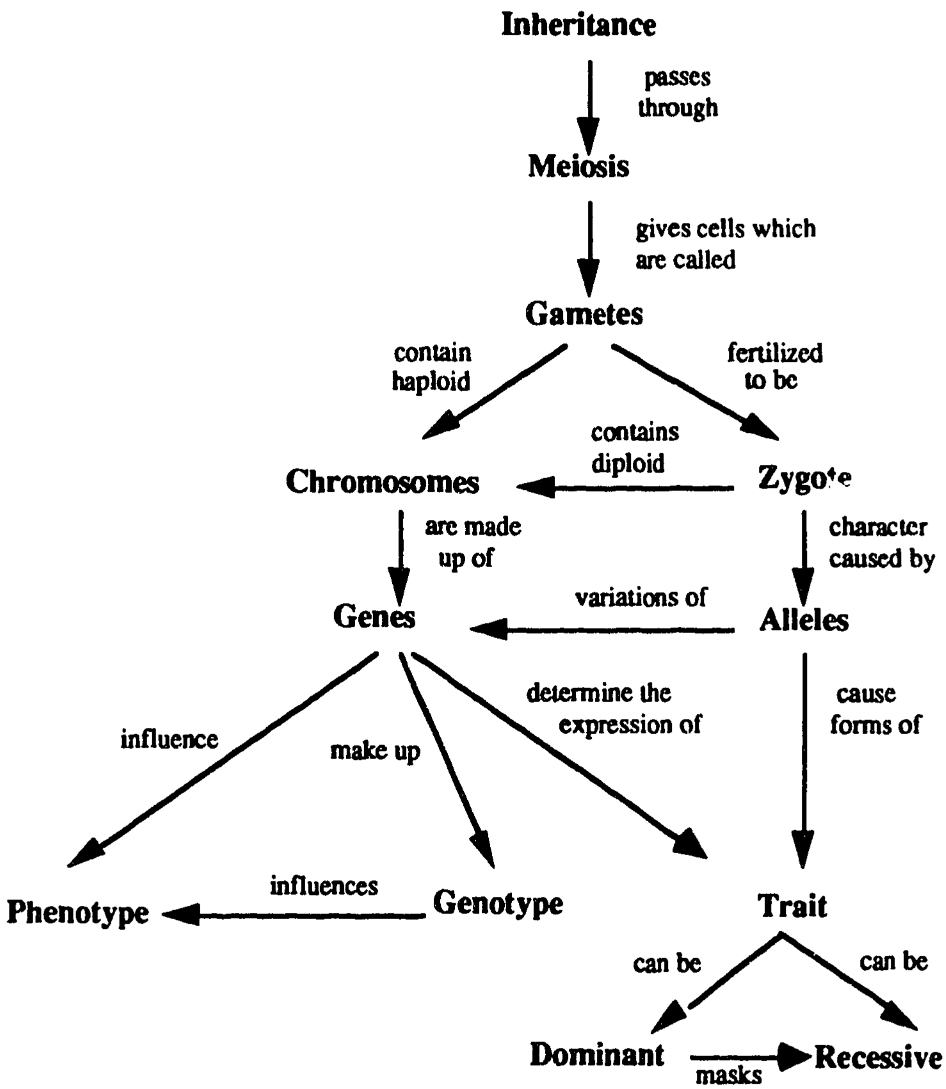
Cross Links:

Cross links show a relationship between concepts on one branch of the hierarchy with concept on another branch. A rating of one point is given for each cross link showing the integration among concepts.

(adapted from Stuart, 1985)

Appendix 2.B

Example of concept map scoring



Scores

Relationship	=	16
Hierarchy	=	6
Branching	=	5
Cross Links	=	5

Appendix 3

Concept evaluation scheme used for scoring the task items

Students' responses to the tasks were grouped into five levels of understanding. The criteria were adapted from the concept evaluation scheme suggested by Westbrook and Marek (1991, 1992). Degrees of understanding were classified and scores given to each category were as follows.

Complete understanding (CU): The student's response contains all information necessary to explain an event or situation in a scientific way = 3 points.

Partial understanding (PU): The student's response contains some accepted scientific ideas. No incorrect information includes in the response = 2 points.

Partial understanding with specific alternative conception (PS): The student's response includes correct information and some alternative conception

= 1 point.

Alternative conception (AC): The student's response demonstrates a complete alternative conception of the idea = 0 point.

No understanding (NU): The student's response consists of irrelevant remarks, the question repeated, or the page left blank = 0 point.

Appendix 4

Training in the concept mapping techniques

Students were introduced to definitions of terms used in concept mapping: concepts, propositions, hierarchy, relationships, cross-links, and general-to-specific examples. They were, then, presented with guidelines for mapping, an example of a concept map, and criteria used to score the map. Students were also given an opportunity to practice the mapping technique through class discussion.

Guidelines for concept mapping

1. Arrange the concepts in a hierarchical manner, beginning with the most general, abstract concept, and proceeding to the most specific, concrete one.

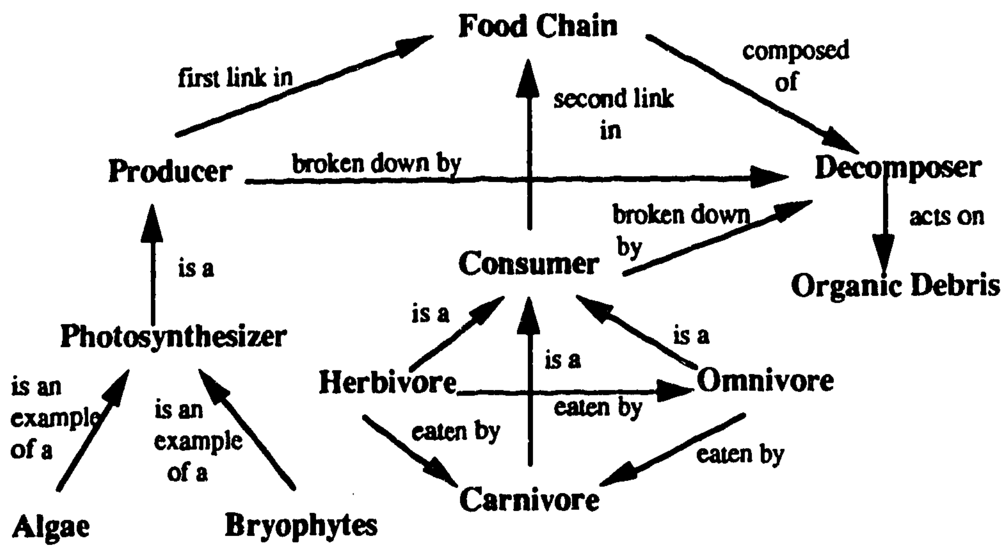
2. Place the most general, abstract concept(s) at the top of the map.

3. Group more specific concepts under the related more general concepts. Concepts of approximately the same generality should be placed on the same hierarchical level.

4. Link related concepts by means of arrows, these lines may be vertically or horizontally (cross-link).

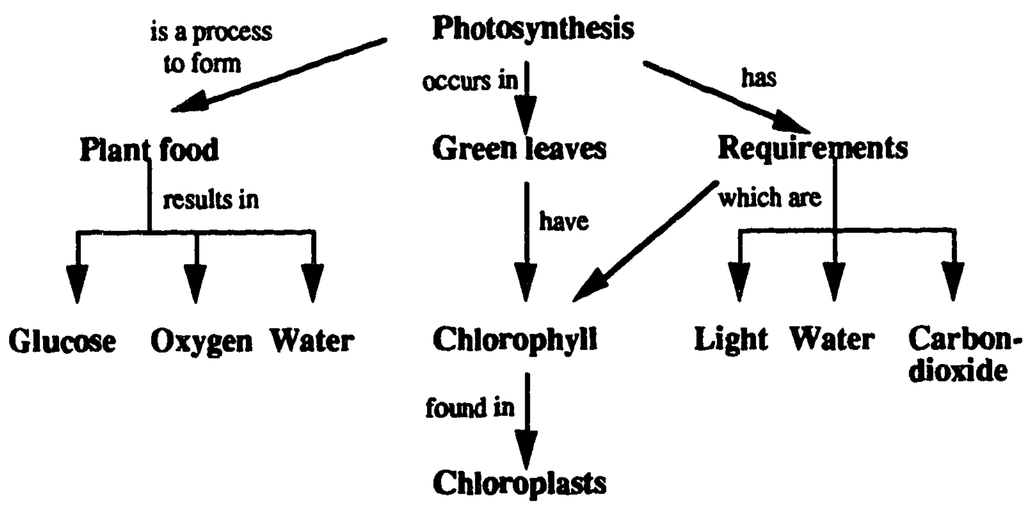
5. Label the lines to form propositions, using words or phrases to show relationship between the two concepts.

Example of a food chain concept map



(after Nocente, 1988)

Concept map used to practice the mapping techniques



Appendix 5

A summary of unit implementation in the three participating classes

Chapter 21

Heredity

Unit overview

The unit was taught after the completion on the units of reproduction and development. It began with description of inherited traits and variation, followed by a discussion of likenesses within relatives. Then, the terms related to the study of heredity were introduced. The rest of the unit focused on genetic problem solving and ends with a delineation of the interaction between heredity and environment. The presentation of activities included discussion, experiments, and problem solving.

Appendix 5 A

Classroom activity format for the cooperatively-designed teaching approach

1. Introduction: comments of lesson's topic or activities or reviews conceptual understanding of the related previous ideas.

2. Development:

   -Lesson focus : presents a focus on a particular concept or problem.

   -Activities : probes students' ideas about concepts, guides students to clarify and exchange their ideas with other students;
   : provides opportunities for students to test their predictions, discover contradictory events, test new scientific ideas, and apply concepts in a variety of situations.

3. Summary : encourages students to summarize the findings and connect the newly learned concepts to previous ideas and/or the next lesson.

Unit outline

Period	Topic
1	Can traits be transmitted from one generation to later generations?
2	Trait variations Patterns of inheritance
3	Dominance and recessiveness Homozygous and heterozygous genes Genotype and phenotype
4	Monohybrid cross
5-6	Dihybrid cross Incomplete dominance
7	Alleles and multiple alleles
8	Heredity and environment Polygenes

Lesson 1. Can traits be transmitted from one generation to later generations?

Introduction : Comments on lesson' s topic and activities.

: Uses a set of transparencies to review sex cell formation, fertilization, and the number of chromosomes in haploid and diploid cells.

Development :

- **Lesson focus**: The offspring has all the characteristics of its species, and it resembles both parents in some ways.

- **Activities**: (T = teacher, S = students)

T : presents a picture of various kinds of fruits and a picture of a group of rock stars.

T : leads to the discussion of "Why are individuals of the same species, both plants and animals, so similar that they have all the characteristics of their own species?"

S : (6-8 students) respond individually.

T : encourages members of the class to compare and contrast their own ideas with those of their classmates.

: suggests students to think if there is anything in the ideas that relate to the evidence of sex cell formation and the fusion of sex cells from two parents.

S : (5-6 students in small groups) compare and contrast individual ideas and make a group conclusion.

: (group representatives) present the results of the group discussion.

T : leads a whole class discussion.

S : are encouraged to compare and contrast to that of the other groups.

T : presents a scientific view using a set of transparencies illustrating sex cell formation and fertilization.

Summary

S : are encouraged to conclude that meiosis is responsible for the fact that we are somewhat like our parents. Through fertilization, offspring gets one set of chromosomes/genes from each parent. A total set of genes contains instructions for the structure and functions of a new individual. That is why organisms resemble their parents.

Assignments

Each student is asked to bring to class the next day, a table of information as follows:

Similarities of appearances within a family

Observed trait	Student	Father	Mother	Brother	Sister	Resembles one of the grandparents?
hair structure	straight/curls					Yes/No
eye lids	1/2 layers					
tongue	roller/ not roller					
ear lobes	lobes/ no lobes					
cheeks	dimple/ no dimple					
hand use	right-handed/ left-handed					

Your height is ....cm.

Your weight is ....kg.

Are you identical to anyone in your family? Why?

Lesson 2: Variation and patterns of inheritance

Introduction: Reviews why the offspring has all the characteristics of its species and resembles both of its parents in some ways.

Development:

- **Lesson focus**: Why the offspring has its own individual characteristics that distinguish it from all other members of the species.

  : Two types of variations.

  : Patterns of inheritance.

- **Activities**: (T = teacher), (S = students)

  T : presents tables on transparencies of total class data summarized from individual student information: one table for height and weight and another for observed traits.

  S : (work in small groups) make graphs from the data and present to the class.

  T : uses the graphs to explain types of variation: continuous and discontinuous.

  : asks, "Why do we not only resemble both of our parents in some ways but also differ from them in other ways?"

  S : (4-6 students) provide their ideas.

  T : writes their answers on the blackboard.

  : presents Mendel's scientific studies which were later replicated by the Thai scientist.

  : asks the students to compare and relate their ideas about differentiation in an individual to the discoveries of those scientists.

  S : (work in small groups of 5-6 students) debate each member's ideas and come to a group decision.

: (group representatives) present the results of the group discussion.

T : leads a whole class discussion.

S : are encouraged to compare and contrast their thinking with that of the other groups.

T : presents a transparency summarizing Mendel's garden peas experiments. A diagram of chromosomes and genes in meiotic division, and fertilization is used to illustrate a cross.

: draws students' attention on the separation of a pair of chromosomes during a gamete formation and a recombination of the pair during fertilization.

Summary

S : are encouraged to verbally summarize that meiosis is responsible for our being genetically unique because a particular combination of chromosomes and genes could happen only once in several million times. Further, the crossing-over of genes on chromosomes contributes even more genetic variability by providing new combination of genes which form a strand of a chromosome.

Assignment

Each student is asked to make a table like the one below to show the characteristics of six people: the student, two siblings (or parents if he or she is the only child in a family), and three friends.

Trait Name	straight/ curling hair	eye lids	ear lobes	dimple	left/right handed	tongue roller
1.						
2.						
3.						
4.						
5.						
6.						

1. Are people more like their family or more like their friends? Why?

2. Are you identical to any of your siblings? Explain why.

Lesson 3: Terminology: "dominant" and "recessive," "homozygous" and "heterozygous genes," and "genotype" and "phenotype."

Introduction: Review Mendel's pea experiments using a diagram of meiotic division.

Development:

- **Lesson focus**: Definition of terms.

- **Activities**: (T = teacher), (S = students)

T : uses a transparency on Mendel's pea experiments to explain definitions of dominant and recessive.

: explains how to use symbols to represent a particular trait.

: explains and gives examples through discussion of how to use symbols for homozygous dominant genes, homozygous recessive genes, and heterozygous genes.

S : practice how to use symbols to represent homozygous dominant genes, homozygous recessive genes, an ;rozygous genes.

T : gives definitions of genotype and phenotype.

S : practice the identification of a genotype and phenotype for each particular trait.

: distinguish and relate the newly learned terms.

Summary

S : summarize the definitions of terms in their own words. Distinguish and relate those terms.

Assignment:

If white fur color is dominant to black, what color would you expect the five offspring born from a white and a black guinea pig to be? Explain your choice.

Lesson 4: Monohybrid cross

Introduction: Review Mendel's pea experiments and terminology.

Development:

- **Lesson focus**: The probability of a monohybrid cross.

- **Activities**: (T = teacher), (S = students)

T : probes 6-8 students on their predictions of the question given as the previous assignment.

: writes their answers on the blackboard.

: asks, "If you toss two coins 20 times, how many combination of heads-heads, heads-tails, and tails-tails would you expect to obtain?"

S : (4-5 students) predict the results.

: (A small group of 5-6 students) conducts an activity used to simulate gamete combination in a monohybrid cross.

: record the results in a table like the one below:

Trial	Possible combinations		
	Heads-Heads	Heads-Tails	Tails-tails
1-5			
6-10			
11-15			
16-20			
Group total			
Class total			

1. What are the actual results for the first five trials?

2. How does the combined class total and ratio compare with your first five trials and your group results? Explain why.

S : share the results of each group with the class.

: compare and discuss their predictions and the actual results.

T : encourages students to compare the investigated results to the predictions they made at the very beginning of the class if:

Tails represents white allele = b
Heads represent black allele = B

S : discuss and debate the results.

T : uses the total class results to theorize about the probability of genetic combination. A set of transparencies which illustrate diagrams of genes and chromosomes are used in an explanation.

Summary:

S : are encouraged to theorize that, since the types of gametes are produced in equal numbers, and if a large number of fertilization occur, all possible combinations will occur in approximately equal numbers.

Assignment:

Review questions p. 104, q. 3-7.

Lesson 5-6 Dihybrid cross and incomplete dominance

Introduction: Review the probabilities in a monohybrid cross, using a diagram of chromosomes and genes.

Development:

- **Lesson focus**: (1) The probability of a dihybrid cross.

- **Activities**: (T = teacher), (S = Students)

T : probes 6-8 students' predictions of, "When considering two pairs of contrasting traits at the same time, what is the ratio of the possible genotypes that might be found in each gamete? Explain your choice.

S : (work in a small group of 5-6) manipulate an investigation to simulate the independent assortment in a dihybrid cross as follows:

(1) put ten red and ten white beads in one bag, and ten yellow and ten green beads in another bag.

(2) pick up one bead each time from each bag for 100 times, record the combination, and return the beads to the bags after each trial.

(3) record the data in a table like the one below:

Counts	Possible combinations			
	Yellow-Red	Yellow-White	Green-Red	Green-White
Group total				
Group ratio				
Class total				
Class ratio				

S : compare and discuss their predictions and the actual results.

T : explains how two pairs of beads were used to simulate gene combination in a dihybrid cross.

S : (work in a small group) predict the genotype ratio of a cross between the heterozygous round-yellow peas and the wrinkle-green peas.

: (work in a small group) make a diagram illustrating chromosomes and genes to support their predictions.

: present their diagrams to the class.

: compare and contrast the diagrams.

Summary:

S : are guided to conclude that genes for different traits are separated and distributed to gametes independently of one another, and that each gamete has equal opportunities to combine during fertilization.

- **Lesson focus**: (2) The incomplete dominant genes produce an intermediate phenotype.

- **Activities**:

T : explains the meaning of the term "incomplete dominance" and shows how to symbolize the genotype.

S : predict possible offspring produced in a cross between red and white coat Shorthorn cattle.

: compare and contrast their predictions with those of other groups.

T : leads a discussion of the scientific view using a transparency diagram of chromosomes and genes.

Summary :

S : determine that the probabilities in a cross involving incomplete dominance are the same as those of a dominant-recessive trait. However, the heterozygous condition produces an intermediate phenotype.

Assignments:

1. Review questions p. 104, q. 9-12.
2. If the mother is blood type A and the father is type B, what are the possible blood types for their child?
3. Bring to the next lesson information about the blood types of each member of the student's family.

Lesson 7: Alleles and multiple alleles

Introduction: Review the concept of incomplete dominance.

Development:

- **Lesson focus** : An allele is one of many possible forms of a gene, and alleles cause contrasting forms of the trait which is determined by a gene.

  : Some traits are determined by more than a single pair of genes. These genes are referred to as multiple alleles.

- **Activities**: (T = teacher), (S = students)

  S : present their predictions for item 2 on their assignments.

  : compare and contrast their predictions with those of other students.

  T : explains the concepts of alleles and multiple alleles and focuses on their relationships to a gene and a trait.

  : presents a set of data on blood types based on information collected from students, asks students to justify the most likely prediction, and then leads a discussion to attain an accurate conceptualization.

  : discusses how to symbolize the genotypes involving multiple alleles.

  S : (work in small groups) make a diagram representing chromosomes and genes involved in the blood type problem to support their predictions.

  : present and debate their diagrams.

  T : leads the class to an accurate conceptualization by a discussion.

Summary:

S: are guided to conclude the definition of an allele. They are also led to conclude that the results of a cross involving multiple alleles can be determined by same process as that used for a monohybrid cross.

Assignments:

1. Give responses to a worksheet on applying the concepts of multiple alleles.

2. Bring to the next lesson information on his/her and parental heights.

Lesson 8: Heredity and environment, and polygenes

Introduction: Review the concept of multiple alleles.

Development:

- **Lesson focus** : Some particular characteristics are determined by two or more different pairs of genes.

  : Genes carry the basic information of all traits, but the phenotypes can be modified by environmental factors.

- **Activities**: (T = teacher), (S = students)

T : asks, "How do the heights of fully grown children compare to their parents ? Why?"

S : (5-6 students) give responses.

T : presents six graphs which are plotted as follows:

(1) male student' s height against the father's height,
(2) male student' s height against the mother's height,
(3) male student' s height against the mean parental heights,
(4) female student' s height against the father's height,
(5) female student' s height against the mother's height, and
(6) female student' s height against the mean parental heights.

S : compare their predictions to the graphs.

T : leads a class discussion on the importance of heredity and environment in the determination of height, focuses on the concept that genes determine the potential of a person, and shows that environment can limit this potential.

S : make a diagram representing genes and chromosomes to illustrate the inheritance of height in each individual student.

T : discusses the concepts of polygenes and emphasizes that these genes cause continuous traits.

S : provide examples of polygenic traits.

Summary

S : are encouraged to determine the differences between multiple alleles and polygenes, and understand the importance of heredity and environment on the development of a person.

Classroom activity format for the teacher-designed teaching approaches (for Class B and C)

1. Introduction: comments of lesson's topic or activities or reviews the knowledge about previous concepts.

2. Development

   - Lesson focus : presents a focus on important points or problems.
   - Activities : introduces the ideas presented in the students' text, asks relevant questions, gives details or examples of the concepts.

     : provides opportunities for students to drill with solving problems.

3. Summary : have students summarize or rephrase the ideas being learned in the lesson.

Appendix 5 B

Unit outline (Class B)

Period	Topic
1-2	Can traits be transmitted from one generation to later generations?
	Trait variations
	Patterns of inheritance
	Dominance and recessiveness
	Homozygous and heterozygous genes
	Genotype and phenotype
3	Monohybrid cross
	Dihybrid cross
4-5	Incomplete dominance
	Alleles and multiple alleles
	Polygenes
	Heredity and environment

Lessons 1-2 : Can traits be transmitted from one generation to later generations?
: Trait variations
: Patterns of inheritance
: Dominance and recessiveness
: Homozygous and heterozygous genes
: Genotype and phenotype

Introduction: Explains the objectives of the unit lessons.

Development:

- **Lesson focus** : Each organism has specific individual characteristics.
  : The offspring and parents are alike.
  : Traits can be classified into two types: continuous and discontinuous variations.
  : Mendel's experiments indicated that all the F_1 generation showed the dominant trait, and the recessive trait reappeared in the F_2 generation in a 3:1 ratio of dominant to recessive.
  : Definitions of related terminology.

- **Activities**: (T = teacher), (S = students)

T : uses the pictures posed on pages 88 and 89 in the students' text in order to lead to the conclusions that (a) each species has particular characteristics and each member of the species has its own specific characteristics that make it different from all other members, and (b) traits can be classified into two types: continuous and discontinuous variations.

S : give examples of continuous variation.

T : asks the students to roll their tongues and give more examples of discontinuous variation.

T : gives a definition of "trait," and explains why siblings are alike.

: discusses the Thai scientist's experiment on sweet basil flowers and Mendel's experiment on garden pea plants.

: explains the terms: "dominance" and "recessiveness," "homozygous" and "heterozygous genes," and "genotype" and "phenotype."

S : take notes as the teacher rephrases definition of the terms.

T : explains how to symbolize the genotype of various traits.

S : define examples given by the teacher.

S : write in their workbook the responses to questions posed on page 94.

T : provides correct answers.

Summary:

T : leads to a conclusion about the focused ideas.

Assignment:

S : perform the experiment 21.1 Continuous traits.

Lesson 3: Monohybid and dihybrid crosses

Introduction: Reviews definition of terms.

Development:

- **Lesson focus** : The F_2 generation consisted of plants that had either the two dominant or the two recessive genes and plants that had one of each. The phenotypic ratio of dominant to recessive traits was 3:1.

  . The genes are distributed independently to the sex cells, and any of the pollen cells has an equal chance to fuse with any one of the egg cells.

- **Activities**: (T = teacher), (S = students)

T : uses Table 21.1 on page 95 of the students' text in order to discuss, "Why the F_2 generation in Mendel's experiments consisted of plants that have a 3:1 ratio of dominant to recessive traits?"

S : respond to the questions, "How many genotypes are there?" and "How many phenotypes are there?"

S : take notes on the meaning of monohybrid cross and the probabilities in the offspring produced in the F_2 generation.

T : discusses Mendel' s experiments of crosses involving two traits.

S : practice symbolizing the genotypes.

T : indicates that a dihybrid parent produce four kinds of gametes. The genes are separated and recombined independently.

: uses a Punnett square and leads a discussion to determine the outcomes of a cross.

Summary:

S : are guided to summarize the number of genotypes and phenotypes of the offspring which result in the F_2 generation of a dihybrid cross.

Lessons 4-5: Incomplete dominance, allele and multiple alleles, heredity and environment, and polygenes.

Introduction: Reviews a dihybrid cross using the diagram on page 98.

Development:

- **Lesson focus:** Incomplete dominance produces an intermediate phenotype in heterozygous individuals.

  : Some traits, such as the ABO blood group, are determined by multiple alleles.

  : Environmental factors influence the expression of genes.

  : Some characteristics are determined by the action of two or more pairs of genes. This polygenic inheritance is often affected by environmental factors.

- **Activities:** (T = teacher), (S = students)

  T : uses the diagram on page 99 in the students' text to explain a cross involving incomplete dominance.

  S : answer the questions on page 100.

  T : explains the definition of an allele and draws a diagram which represents each pair of alleles on the blackboard.

  : discusses the concepts of multiple alleles and emphasizes that three genes associated with blood type produce six combinations of pairs but result in only four human blood types.

  S : write in their workbook the responses to the questions on page 101.

  T : corrects the answers.

  : uses diagrams on page 101 and 102 to discuss how environmental factors can influence genetic traits.

T : explains the concepts of polygenes and the continuous traits which result from various combinations of these gene pairs.

S : write in their workbook the responses to the questions posed on page 103.

T : corrects the answers.

Summary

T : summarizes the main points.

Appendix 5 C

Unit outline (Class C)

Period	Topic
1	Can traits be transmitted from one generation to later generations? Trait variations
2	Patterns of inheritance Dominance and recessiveness Homozygous and heterozygous genes Genotype and phenotype
3	Monohybrid cross
4-5	Dihybrid cross Incomplete dominance Alleles and multiple alleles
6	Heredity and environment Polygenes

Lesson 1 : Can traits be transmitted from one generation to later generations?
: Trait variations.

Introduction: Explains the objectives of the unit lessons.

Development:

- **Lesson focus** : Each species has particular characteristics.

  : Trait variation can be classified into two types: continuous and discontinuous variations.

- **Activities**: (T = teacher), (S = students)

  T : uses the pictures on pages 88 and 89 in the students' text in order to discuss and lead to the following conclusions:

  (1) each species has particular characteristics, and
  (2) traits can be classified into two types-continuous and discontinuous variations.

  S : respond to questions the teacher raises in the discussion.

  T : specifies examples of continuous and discontinuous variations from students' particular characteristics.

Summary:

T : leads to a conclusion about the focused ideas.

Assignment:

S : perform experiments 21.1 and 21.2: Continuous and discontinuous traits.

Lesson 2 : Patterns of inheritance
: Dominance and recessiveness
: Homozygous and heterozygous genes
: Genotype and phenotype

Introduction : Reviews types of variation.
: Comments on how the graphs plotted in an assignment should appear.

Development:

- **Lesson focus** : Each species has specific characteristics and individuals of the same species are different from each other. These differences can be classified into two types: continuous and discontinuous variations.

: Mendel's experiments indicated that all the F_1 generation had the dominant trait, and the recessive trait reappeared in the F_2 generation in a 3:1 ratio of dominant to recessive.

: Definitions of related terms.

- **Activities** : (T = teacher), (S = students)

T : explains the concept of inherited traits.

: introduces the Thai scientist's experiment on sweet basil flowers then leads to a discussion of the results Mendel found in his experiments on garden pea plants, focusing on the phenotypic ratio of the offspring in the F_1 and F_2 generations.

S : summarize definitions of the terms "dominant" and "recessive."

T : explains definition of the terms "heterozygous," "homozygous genes," "genotype," and "phenotype."

Summary

T : summarizes how to symbolize the genotypes of homozygous dominant/ recessive, and heterozygous traits.

Lesson 3: Monohybid cross.

Introduction: Reviews definition of terms.

Development:

- **Lesson focus**: The possible gamete types produce by a parent of a particular genotype.

  : The F_2 generation consisted of plants that had either the two dominant or the two recessive genes and plants that had one of each. The phenotypic ratio was 3:1 of dominant to recessive traits.

- **Activities**: (T = teacher), (S = students)

  T : explains how the results of Mendel's experiments conform with the recent concepts of meiosis and fertilization.

  S : discuss the possibility of gamete types produce by parents of various genotypes.

  T : explains the meaning of a "monohybrid cross," then leads a discussion about the genotypic and phenotypic ratios of the offspring in the F_1 and F_2 generations.

Summary

T : summarizes the main ideas taught in the lesson.

Lessons 4-5: Dihybrid cross, incomplete dominance, allele and multiple alleles, and heredity and environment.

Introduction: Probes students' understanding of the possible gamete types produced by a parent with a particular genotype.

Development:

- **Lesson focus** : The F_2 generation consisted of plants that had either the two dominant or recessive genes and plants that had one of each. The phenotypic ratio was 3:1 of dominant to recessive traits.

  : The genes are distributed independently to the sex cells. As well, anyone of the sperm cells has an equal chance to fuse with anyone of the egg cells.

  : Some traits have different inherited pattern from what Mendel had found, for example, the inheritance involving incomplete dominance.

  : Some traits are determined by multiple alleles such as the ABO blood group.

  : Environmental factors can support or limit the expression of genes.

- **Activities:** (T = teacher), (S = students)

  T : asks the students to predict possible gamete types of a dihybrid parent.

  : uses a Punnett square to determine and discuss the results of a cross between two dihybrid parents.

  S : take notes as the teacher concludes that:

  (1) A gene is a unit which controls heredity.

  (2) Genes are independently distributed to the sex cells.

  (3) Any one of the sperm cells can fertilize any one of the egg cells to form a zygote, therefore, probability in the offspring ratio is the chance of random fertilization.

T : explains the genotypic and phenotypic ratios of the offspring in the F_1 and F_2 generations concerning the incomplete dominant trait.

: probes students' understanding of the concepts using the questions posed in the students' text.

S : respond to the questions.

T : explains the definition of an "allele" and discusses the concept of "multiple alleles."

S : do the exercise on page 101.

: discuss the results.

T : discusses the influence of environmental factors heredity, focuses on the idea that genetic factors do not change but environmental factors can support or limit the expression of genes.

Summary

T : concludes the main points.

Lessons 6: Polygenes.

Introduction: Reviews that the previous examples of inheritance involved traits that are determined by a single pair of chromosomes.

Development:

- **Lesson focus** : Some characteristics are determined by the action of two or more pairs of genes.

  : The possible genotypes of gametes produced by a heterozygous polygenic trait parent can be determined by a formula 2^n, where n = a number of gene pairs involved in a problem.

- **Activities**: (T = teacher), (S = students)

  T : introduces a concepts of polygenes.

  S : discuss the possible genotypes of gametes produced by a polygenic trait parent.

  : write in their workbook the responses to the questions on page 103.

  T : discusses the answers.

Summary

T : reviews the main ideas of total unit.

Appendix 6

Table 15: Percentage of Students' Responses to Written Tasks four Months after Instruction

	Items	U Level	Class A (35)	Class B (27)	Class C (36)
2.1	The difference between environmental and hereditary characteristics.	CU	80.00 (n=28)	29.63 (n=8)	50.00 (n=18)
		PU	5.71 (n=2)	40.74 (n=11)	36.11 (n=13)
		PS	0.0 (n=0)	0.0 (n=0)	0.0 (n=0)
		AC	11.43 (n=4)	14.81 (n=4)	8.33 (n=3)
		NR	2.86 (n=1)	14.81 (n=4)	5.[illegible] (n=2)
2.2	The effect of time on the possibility of inheritance of acquired characteristics.	CU	51.43 (n=18)	29.63 (n=8)	41.67 (n=15)
		PU	5.71 (n=2)	22.22 (n=6)	36.11 (n=13)
		PS	0.0 (n=0)	0.0 (n=0)	0.0 (n=0)
		AC	40.00 (n=14)	33.33 (n=9)	5.56 (n=2)
		NR	2.86 (n=1)	14.81 (n=4)	16.67 (n=6)
3.1	Probability in inheritance.	CU	42.86 (n=15)	0.00 (n=0)	36.11 (n=13)
		PU	40.00 (n=14)	29.63 (n=8)	33.33 (n=12)
		PS	8.57 (n=3)	48.15 (n=13)	11.11 (n=4)
		AC	5.71 (n=2)	3.70 (n=1)	0.00 (n=0)
		NR	2.86 (n=1)	18.52 (n=5)	19.44 (n=7)

Items	U Level	Class A (35)	Class B (27)	Class C (36)
3.2 The equality of genetic contribution of each parent in sexual reproduction.	CU	28.57 (n=10)	3.70 (n=1)	11.11 (n=4)
	PU	31.43 (n=11)	7.41 (n=2)	22.22 (n=8)
	PS	37.14 (n=13)	81.48 (n=22)	58.33 (n=21)
	AC	0.0 (n=0)	3.70 (n=1)	8.33 (n=3)
	NR	2.86 (n=1)	3.70 (n=1)	0.00 (n=0)
4.1 The likenesses within a family	CU	37.14 (n=13)	7.41 (n=2)	2.78 (n=1)
	PU	57.14 (n=20)	70.37 (n=19)	83.33 (n=30)
	PS	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)
	AC	0.00 (n=0)	22.22 (n=6)	0.00 (n=0)
	NR	5.71 (n=2)	0.00 (n=0)	13.89 (n=5)
4.2 The variation within a family	CU	5.71 (n=2)	0.00 (n=0)	5.56 (n=2)
	PU	82.86 (n=29)	59.26 (n=16)	52.78 (n=19)
	PS	2.86 (n=1)	0.00 (n=0)	11.11 (n=4)
	AC	2.86 (n=1)	14.81 (n=4)	11.11 (n=4)
	NR	5.71% (n=2)	25.93% (n=7)	19.44% (n=7)

Items		U Level	Class A (35)	Class B (27)	Class C (36)
5.1	What genes are.	CU	11.43 (n=4)	0.00 (n=0)	2.78 (n=1)
		PU	80.00 (n=28)	81.48 (n=22)	75.00 (n=27)
		PS	8.57 (n=3)	18.52 (n=5)	16.67 (n=6)
		AC	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)
		NR	0.00 (n=0)	0.00 (n=0)	5.56 (n=2)
5.2	Where genes are located.	CU	91.43 (n=32)	92.59 (n=25)	86.11 (n=31)
		PU	8.57 (n=3)	7.41 (n=2)	5.56 (n=2)
		PS	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)
		AC	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)
		NR	0.00 (n=0)	0.00 (n=0)	8.33 (n=3)
5.3	How genes are functioned.	CU	2.86% (n=1)	0.00% (n=0)	2.78% (n=1)
		PU	31.43% (n=11)	14.81% (n=4)	2.78% (n=1)
		PS	2.86 (n=1)	0.00 (n=0)	2.78 (n=1)
		AC	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)
		NR	62.86 (n=22)	85.19 (n=23)	91.67 (n=33)

Items		U Level	Class A (35)	Class B (27)	Class C (36)
6.1	The possibility of phenotypic change in the inheritance of human athletic skills.	CU	54.29 (n=19)	11.11 (n=3)	44.44 (n=16)
		PU	31.43 (n=11)	29.62 (n=8)	47.22 (n=17)
		PS	11.43 (n=4)	22.22 (n=6)	2.78 (n=1)
		AC	2.86 (n=1)	33.33 (n=9)	0.00 (n=0)
		NR	0.00 (n=0)	3.70 (n=1)	5.56 (n=2)
6.2	The effect of time on the possibility of inheritance of athletic skills.	CU	22.86 (n=8)	11.11 (n=3)	36.11 (n=13)
		PU	20.00 (n=7)	29.63 (n=8)	27.78 (n=10)
		PS	8.57 (n=3)	29.63 (n=8)	2.78 (n=1)
		AC	48.57 (n=17)	25.93 (n=7)	30.56 (n=11)
		NR	0.00 (n=0)	3.70 (n=1)	2.78 (n=1)
7.1	The segregation of alleles during meiosis	CU	14.29 (n=5)	0.00 (n=0)	2.78 (n=1)
		PU	62.86 (n=22)	37.04 (n=10)	55.56 (n=20)
		PS	8.57 (n=3)	7.41 (n=2)	8.33 (n=3)
		AC	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)
		NR	14.29 (n=5)	55.56 (n=15)	33.33 (n=12)

Items		U Level	Class A (35)	Class B (27)	Class C (36)
7.2	Problem solving on the monohybrid cross.	CU	28.57 (n=10)	0.00 (n=0)	0.00 (n=0)
		PU	57.12 (n=20)	66.67 (n=18)	80.56 (n=29)
		PS	8.57 (n=3)	22.22 (n=6)	8.33 (n=3)
		AC	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)
		NR	5.71 (n=2)	11.11 (n=3)	11.11 (n=4)
8.1	The relationships between the height of a son and the heights of his parents.	CU	8.57 (n=3)	0.00 (n=0)	0.00 (n=0)
		PU	71.43 (n=25)	88.89 (n=24)	83.33 (n=30)
		PS	14.29 (n=5)	3.70 (n=1)	8.33 (n=3)
		AC	0.00 (n=0)	7.41 (n=2)	5.56 (n=2)
		NR	5.71 (n=2)	0.00 (n=0)	2.78 (n=1)
8.2	The relationships between the height of a daughter and the heights of her parents.	CU	8.57 (n=3)	0.00 (n=0)	2.78 (n=1)
		PU	65.71 (n=23)	70.37 (n=19)	80.56 (n=29)
		PS	20.00 (n=7)	11.11 (n=3)	8.33 (n=3)
		AC	0.00 (n=0)	18.52 (n=5)	5.56 (n=2)
		NR	5.71 (n=2)	0.00 (n=0)	2.78 (n=1)

	Items	U Level	Class A (35)	Class B (27)	Class C (36)
9.1	Problem solving on the dihybrid crosses.	CU	25.71 (n=9)	0.00 (n=0)	16.67 (n=6)
		PU	0.00 (n=0)	0.00 (n=0)	2.78 (n=1)
		PS	8.57 (n=3)	0.00 (n=0)	5.56 (n=2)
		AC	2.86 (n=1)	14.81 (n=4)	0.00 (n=0)
		NR	62.86 (n=22)	85.19 (n=23)	75.00 (n=27)
9.2	The segregation and recombination of alleles.	CU	5.71 (n=2)	0.00 (n=0)	0.00 (n=0)
		PU	11.43 (n=4)	0.00 (n=0)	5.56 (n=2)
		PS	2.86 (n=1)	0.00 (n=0)	0.00 (n=0)
		AC	5.71 (n=2)	14.81 (n=4)	0.00 (n=0)
		NR	74.29 (n=26)	85.19 (n=23)	94.44 (n=34)
10.1	A number of alleles for a gene.	CU	28.57 (n=10)	0.00 (n=0)	8.33 (n=3)
		PU	0.00 (n=0)	0.00 (n=0)	0.00 (n=0)
		PS	2.86 (n=1)	3.70 (n=1)	13.89 (n=5)
		AC	51.43 (n=18)	40.74 (n=11)	19.44 (n=7)
		NR	17.14 (n=6)	55.56 (n=15)	58.33 (n=21)

Items	U Level	Class A (35)	Class B (27)	Class C (36)
10.2 A number of alleles in a diploid cell.	CU	28.57 (n=10)	0.00 (n=0)	2.78 (n=1)
	PU	17.14 (n=6)	0.00 (n=0)	5.56 (n=2)
	PS	14.29 (n=5)	0.00 (n=0)	0.00 (n=0)
	AC	14.29 (n=5)	7.41 (n=2)	11.11 (n=4)
	NR	25.71 (n=9)	92.59 (n=25)	80.56 (n=29)
10.3 A number of alleles in a sex cell.	CU	17.14 (n=6)	0.00 (n=0)	0.00 (n=0)
	PU	11.43 (n=4)	0.00 (n=0)	8.33 (n=3)
	PS	5.71 (n=2)	0.00 (n=0)	2.78 (n=1)
	AC	40.00 (n=14)	7.41 (n=2)	11.11 (n=4)
	NR	25.71 (n=9)	92.59 (n=25)	77.78 (n=28)
11.1 The possible genotypes of the father's blood groups.	CU	20.00 (n=7)	0.00 (n=0)	2.78 (n=1)
	PU	331.43 (n=11)	14.81 (n=4)	19.44 (n=7)
	PS	22.86 (n=8)	40.74 (n=11)	27.78 (n=10)
	AC	0.00 (n=0)	0.00 (n=0)	2.78 (n=1)
	NR	25.71 (n=9)	44.44 (n=12)	47.22 (n=17)

Items		U Level	Class A (35)	Class B (27)	Class C (36)
11.2	The blood types that the father could not have.	CU	11.43 (n=4)	11.11 (n=3)	0.00 (n=0)
		PU	17.14 (n=6)	0.00 (n=0)	5.56 (n=2)
		PS	25.71 (n=9)	40.74 (n=11)	22.22 (n=8)
		AC	5.71 (n=2)	0.00 (n=0)	5.56 (n=2)
		NR	40.00 (n=14)	48.15 (n=13)	66.67 (n=24)

Appendix 7

Table 16: Results of multiple analysis of variance of mean scores by group and session.

Session	I	II	III	IV	V
Max. scores	27	18	27	60	66
Class A	12.885 (47.72%)	9.257 (51.43%)	6.114 (22.64%)	35.857 (59.76%)	35.971 (54.50%)
Class B	13.486 (49.95%)	8.571 (47.62%)	4.833 (17.90%)	26.514 (44.19%)	23.815 (36.08%)
Class C	14.442 (53.49%)	5.615 (31.20%)	3.419 (12.66%)	28.929 (48.22%)	28.722 (43.52%)

SESSION	CLASS					
I	B	FREQ	(37.0)	REQ DIFF	2.92	
		ESTMEAN	13.51	OBS DIFF	0.66	
				S.E.	0.74	
				D.F.	321.18	
				SCHEFFE	3.97	
	C	FREQ	(43.0)	REQ DIFF	2.82	2.78
		ESTMEAN	14.44	OBS DIFF	1.59	0.93
				S.E.	0.71	0.70
				D.F.	321.18	321.18
				SCHEFFE	3.97	3.97
	ESTMEAN				12.86	13.51
	FREQUENCIES				(35.0)	(37.0)
	CLASS				A	B
	SESSION				I	I

(*) denotes pairs of groups significantly different at the 0.050 level.

SESSION	CLASS					
II	B	FREQ	(35.0)	REQ DIFF	2.96	
		ESTMEAN	8.60	OBS DIFF	0.63	
				S.E.	0.75	
				D.F.	323.10	
				SCHEFFE	3.97	
	C	FREQ	(39.0)	REQ DIFF	2.88	2.87
		ESTMEAN	5.62	OBS DIFF	3.61*	2.98*
				S.E.	0.73	0.72
				D.F.	324.18	325.77
				SCHEFFE	3.97	3.97
	ESTMEAN				9.23	8.60
	FREQUENCIES				(35.0)	(35.0)
	CLASS				A	B
	SESSION				II	II

SESSION	CLASS					
III	B	FREQ	(36.0)	REQ DIFF	2.94	
		ESTMEAN	4.86	OBS DIFF	1.23	
				S.E.	0.74	
				D.F.	322.16	
				SCHEFFE	3.97	
	C	FREQ	(43.0)	REQ DIFF	2.82	2.80
		ESTMEAN	3.42	OBS DIFF	2.66	1.44
				S.E.	0.71	0.71
				D.F.	321.18	322.26
				SCHEFFE	3.97	3.97
	ESTMEAN				6.09	4.86
	FREQUENCIES				(35.0)	(36.0)
	CLASS				A	B
	SESSION				III	III

(*) denotes pairs of groups significantly different at the 0.050 level.

SESSION	CLASS					
IV	B	FREQ	(37.0)	REQ DIFF	5.14	
		ESTMEAN	26.55	OBS DIFF	9.28*	
				S.E.	1.53	
				D.F.	190.87	
				SCHEFFE	3.36	
	C	FREQ	(42.0)	REQ DIFF	4.99	4.92
		ESTMEAN	28.93	OBS DIFF	6.90*	2.38
				S.E.	1.48	1.46
				D.F.	190.87	190.87
				SCHEFFE	3.36	3.36
	ESTMEAN				35.82	26.55
	FREQUENCIES				(35.0)	(37.0)
	CLASS				A	B
	SESSION				IV	IV

SESSION	CLASS					
V	B	FREQ	(27.0)	REQ DIFF	5.46	
		ESTMEAN	23.85	OBS DIFF	12.09*	
				S.E.	1.62	
				D.F.	202.63	
				SCHEFFE	3.36	
	C	FREQ	(36.0)	REQ DIFF	5.12	5.37
		ESTMEAN	28.72	OBS DIFF	7.22*	4.87
				S.E.	1.52	1.60
				D.F.	197.07	205.22
				SCHEFFE	3.36	3.36
	ESTMEAN				35.94	23.85
	FREQUENCIES				(35.0)	(27.0)
	CLASS				A	B
	SESSION				V	V

(*) denotes pairs of groups significantly different at the 0.050 level.