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Learning Difficulties in Genetics and the Development of Related Attitudes in Taiwanese Junior High Schools

By

Yu-Chien Chu

B.S., M.S.

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Centre for Science Education
Educational Studies, Faculty of Education
University of Glasgow, United Kingdom

Abstract

This study seeks to explore the problems of genetics learning and to identify possible ways forward. The work was carried out at junior high school level in Taiwan.

Genetics is often thought of as a subject or a topic in biology that is difficult to learn and understand, especially for novices. A review of literature on learning difficulties in genetics is provided to explore the nature of the difficulties, with likely explanations for the difficulties observed.

Undoubtedly, many would acknowledge that genetics is an important subject to learn in these days and age where its applications are ubiquitous and even the cause of many debates. However, due to the nature of the subject matter and the way learning processes occur and, possibly, the way it is being taught, the understanding of genetics ideas of the majority of students is thought to be very poor and full of confusions and alternative views.

Thus, the overall aim of this study is to explore learning difficulties and problems in genetics and then to develop and test ways by which the situation might be improved. The research for this thesis was carried out in three stages.

In the first stage, the adolescent learners' preconceptions about genetics were explored before they move to the formal course. The result indicated that the essential foundational concepts, such as structure and function of cells and its organelles, cell divisions (mitosis and meiosis), reproduction, and basic mathematical requirements and the concept of probability, are generally vague and misconceptions are widespread.

In the second stage, factors that might affect the learning of genetics for adolescent learners were investigated. The factors were prior knowledge related to genetics and the effects of the limitation of learners' psychological characteristics (namely, perceptual fields or the degree of field dependence and the working memory space). Results showed that students' performance in genetics examination revealed a significant correlation with their prior knowledge, the working memory capacity and the degree of field dependence.

Based on the findings from the first and second stage of the research, a set of teaching material of genetics course for the first year of junior high school students was developed in the third stage. The teaching material was deliberately constructed not only to minimise demands on the working memory, but also to encourage attitude development. The performance of students was found to be significantly better than for those who had been taught by the traditional approaches. Numerous comparisons of attitudes between the two groups revealed that attitudes of social awareness as well as attitudes towards aspects of the learning processes involved were more positive for those who had used the new materials

It should be pointed out that all conclusions derived from this study must be treated tentatively. Inevitably, any new approach will have a novelty factor which may enhance performance. Nonetheless, the evidence taken together does support the hypothesis that learning arranged in line with information processing insights is more effective. In addition, the strategies used were designed in line with understandings of the ways attitudes develop and the effectiveness of these approaches has been demonstrated. Overall, the study has highlighted several problems and, on the basis of the evidence obtained, suggests possible ways forward for a better approach to genetics learning.

Acknowledgement

Studying in the Centre for Science Education in the University of Glasgow has been an immense experience for me, which has a significant effect on my views of research and the whole life. This study does not only belong to me but also those without whose generous help and support this research could not have succeeded.

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Chapter One

Introduction

1.1 Introduction

Learning is not just the transferring of knowledge from the teacher to the learner. It is an understanding process where relatively permanent changes are caused by information and experience. These changes do not solely refer to outcomes of the learner's behaviour that are manifestly observable, but also to attitudes, feelings and intellectual processes that may not be so obvious (Hamachek, 1995; Atkinson *et al.*, 1993).

Learning for understanding can be achieved if educators make the effort to find out what students' conceptions of learning are and what constitutes understanding. Thus, this study had sought to explore the learning difficulties in genetics and to identify possible ways forward.

In this chapter, a brief outline of the education system in the Republic of China (R.O.C.) in Taiwan will be offered in order to become familiar with the educational environment from which the sample for this research comes. After that, the purpose and structure of this research study will be described.

1.2 Education system in Taiwan

The current education system in Taiwan involves basic education, intermediate education, and advanced education (Ministry of Education of Taiwan, 2007) (Figure 1-1). Basic education includes kindergartens, national primary and national junior high schools. Intermediate education includes vocational high schools and senior high schools. Advanced education includes junior colleges, universities and graduate schools.

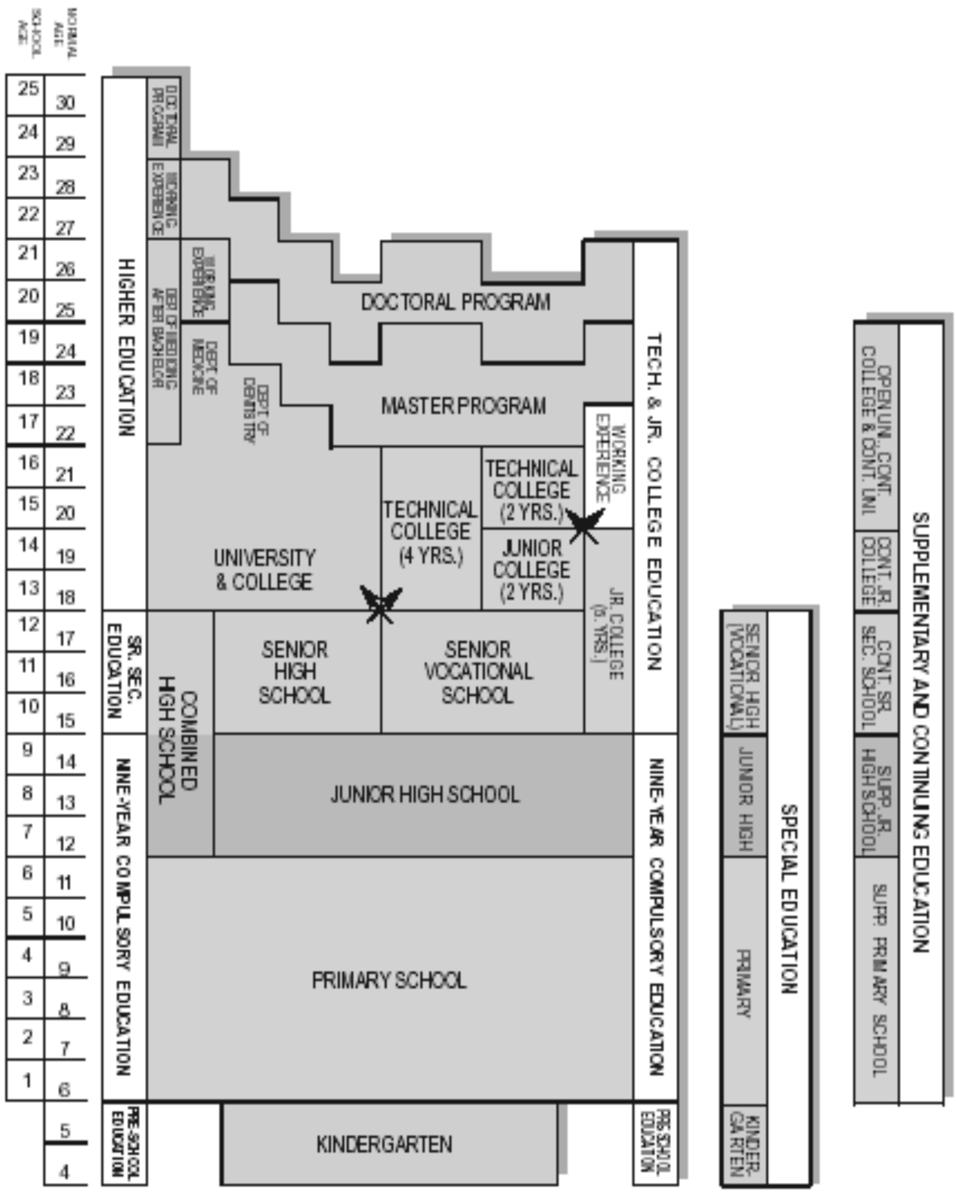


Figure 1-1: Education system in Taiwan.

Ministry of Education of Taiwan, 2007

The educational process, normally, requires two years of preschool education, six years of primary school, three years of junior high school, three years of senior high school, four years of college or university, two years of a graduate school programme, and four years of a doctoral degree programme. Most schools are mixed gender and there are no ethnicity differences. Children start to go to school at the age of six and receive nine years compulsory education at primary school and junior high school without taking entrance examination (the enrolment rate is very close to 100%).

After that, students may choose an academic track or a vocational track. This may involve senior high school, university, and postgraduate programme education or vocational high school, junior college, and university of technology education. Admission into all of these institutions is by competitive entrance examinations.

For preparing children to meet the challenges of the 21st century, the Taiwan government has engaged in educational reforms since 2000. This relates to the *Nine-Year Integrated Curriculum* for primary and junior high school education. Traditionally, everything was decided by the government, anything from the standard curriculum and the school uniform. However, the government now just decides the general guidelines of the curriculum and empowers the local governments, schools, and teachers to decide the teaching materials depending on respective needs of various students.

In addition, all subjects are integrated into seven major learning areas. The aim is to achieve mastery through a comprehensive study of the subjects. Included are language, physical education and health, society, arts, mathematics, science and technology, and combined activities. The subject of science and technology is introduced in the third year of primary school (around aged 8-9) and it covers chemistry, physics, biology, earth science, computer science, and technology.

1.3 Purpose of the research study

During the past two decades, the knowledge of genetics and biotechnology has increased exponentially. Scientists have tried to apply the new discoveries in medicine and agriculture to profit the society. However, several recent developments are controversial, such as therapeutic cloning and genetically modified food (GM food). As citizens, people should deal with scientific debates in order to contribute to decision-making about issues, whether these are personal or political. In fact, for many people, developments in genetics are no longer equated with the idea of progress.

Science education aims not only to provide students with a basic understanding of science concepts, offering insights and understandings about the world around them. However, it also aims to promote a positive attitude towards engaging with science and cultivate a person's development of scientific literacy. The study of genetics can offer insights into the way the living world works. The impact of recent genetics research on medicine, food production, health and lifestyles is considerable and it can be argued that every citizen must have some understanding of the issues involved.

However, any review of the literature about school and university students in learning genetics leads to the inescapable conclusion that students consider genetics difficult to learn and many misconceptions and misunderstandings can arise. Overall, genetics is an important theme for all learners but it is an area where there are major difficulties in understanding.

Thus, the purpose of this study is to investigate the situation relating to learning of genetics in junior high schools in Taiwan, to offer strategies and approaches which will reduce students' difficulties in genetics, these being based on the accepted understanding of psychological reasons which bring about difficulties for students. Using established models of learning and research evidence about learning in sciences, the aim is to test some ways forward which are likely to improve the situation in the learning of genetics in Taiwan. This testing will involve not only the investigation of student performance in genetics tests but will also seek to explore the ways attitudes are affected by the new approaches.

Although set in Taiwan, the problems are in no way unique to the Taiwanese or their educational system. Thus, the findings should be able to be applied, at least in general terms, in other countries and other educational systems.

The research study was carried out in three stages over a period of two years with the same age group of junior high school students. Junior high students were chosen because this is the only time when genetics is taught to all the students in a year group in Taiwan. Genetics courses at later stages are only offered to those who have elected to take biology.

In the first stage, the conceptions that students have concerning some basic aspects related to genetics were explored in order to obtain an insight into the underpinning ideas before they receive tuition on genetics. The second stage of research investigated some psychological factors influencing students learning in genetics. In the light of the findings in the former stages, the third stage was devoted to developing a series of instructional approaches to improve students' conceptual understanding of genetics, to encourage more positive attitudes, and to be aware of more social implications of genetics.

1.4 Structure of the thesis

First of all, a review of relevant aspects of the literature is offered. This looks at the nature of genetics against a background of how learning occurs. Afterwards, the methodology of this research and results and discussions of the findings from the study are presented.

In more detail:

- Chapter two discusses the aims of science education, especially in the field of biology/genetics. Included are scientific literacy and attitudes to science as well as the approach to them.

- Chapter three reviews science education literature on the difficulties and problems when learning genetics, which are attributed to a variety of reasons: the nature of scientific knowledge, the ingrained misconceptions, the complexity nature of genetics, the extensive and abstract terminology of genetics, and mathematical content involved.

- Chapter four reviews some of the learning models, which relate to observations on learning processes in the face of difficulties in the field of science education. These include Piaget's cognitive development theory, Ausubel's meaningful learning model, and the information processing model.

- Chapter five describes the methods by which the study was carried out. The techniques are introduced against the background of the literature, but also the way they are used, along with the strengths and weaknesses.

- Chapter six shows in detail the first stage of the study. It focuses on the investigation into students' prior knowledge in genetics.

- Chapter seven describes in detail the second stage of the study, which investigated aspects of psychological factors that influence genetics learning. The working memory capacity and field dependence/field independence were the main focus of this study.

- Chapter eight describes in detail the third stage of the study. It involves the development of a set of the teaching material, designed specially to improve genetics learning in order to cater for this modern society.

- Finally, chapter nine draws the conclusions and makes suggestions for teaching and further research on the basis of the results from above studies.

Chapter Two

Aims of Biology Education

2.1 Introduction

Biology, from Greek *bios* (life) and *logos* (word or discourse), is the science of life and the science of living organisms. Evidences of early human observations of nature were seen in prehistoric cave art. The history of biology dates as far back as the rise of various civilizations as classic philosophers had their own ways of using biology as a system of understanding life. Aristotle, one of the most prolific natural philosophers of antiquity, made countless observations and classifications of plants and animals in the world around him. Over the years, in the quest to observe, describe, and explain natural phenomena by many researchers, there has amassed a great deal of knowledge and facts.

The invention of the microscope in the late 17th century caused a revolution in the science of life by revealing otherwise invisible and previously unsuspected worlds. It has broadened and deepened the scope of biology, also creating the science of microbiology. In 1953, Watson and Crick discovered the chemical structure of DNA and started a new branch of science, molecular biology. Since then, biology research and its applications have grown rapidly and developed widely.

Since man is a social being, his universal social currencies are often transmitted from person to person and from generation to generation. Science as one of the social currencies needs to be thus transmitted. Science education is designed to develop in learners a rich and full understanding of the inquiry process, the key concepts and principles of science, and also the skills to identify and to solve scientific problems based on what is known and even to do research into new areas of knowledge. According to Willington (1988):

> *Science education is primarily concerned with transmitting a body of inherited knowledge…In the 'information age' all that matters is that pupils know how to access information and where to acquire the facts…The most valuable part of a science education is what remain after facts have been forgotten.*

2.2 Aims in learning biology

One of the important reasons for emphasis on science is the perceived need to maintain a pool of qualified people from whom the scientists, technologists, engineers, and technicians of the future may be drawn. However, many facts have showed that most people who have studied science at school do not go on to use their science knowledge and skills directly in their future careers.

There is an example about the situation of studying chemistry in Scotland described by Reid (1999). He noted that, for every 100 pupils at early secondary level (12-13 years old), 40 pupils are most likely to pursue chemistry at aged 14-15 (40%). By the age of 16-17 (the top of secondary level), about 20 pupils continue to learn chemistry (20%). However, Reid cautioned that, despite the popularity of chemistry at secondary level, perhaps only 1% goes on to a degree related to chemistry, with, perhaps, another 2% taking a degree heavily dependent on chemistry. These figures are relatively similar to those associated with physics and biology.

On this basis, there is no support for the notion that secondary school pupils should take science in order to prepare them to be scientists or related professions. That science to be taught at each level is determined by the requirement of the level above is the wrong approach, because the population at the next level up is only a tiny fraction of the level under consideration (Reid, 2000).

In fact, in recent years, science educators and curriculum developers have realised that science is carried out in school education not only to prepare pupils for university advanced studies or the future careers in science, but also to cultivate them to be citizens in the society which is now highly dependent upon scientific and technological advances

(Kesner *et al.*, 1997). The Scottish Science Advisory Committee (SSAC, 2003) stated the objectives for science education in Scotland:

- *Science education is to provide an excellent supply of young engineers, scientists and trades personnel; and*
- *Science education is to raise and to extend the general level knowledge, understanding and awareness of science and technology in the population as a whole.*

In general, the second objective is much more important in that it applies to everyone. The first objective is for a minority. However, the minority involves future professionals in science-related activities and can not be overlooked.

In addition, the importance of awareness of social implications in science also has been showed up many recent proposals for transforming science education, which call for increased focuses on debatable, socially relevant issues and the relevance of science to daily life within the science curriculum (Hodson, 2003; Zeidler, 2003; Kolsto, 2001).

Regarding these, education has no higher purpose than preparing people to lead personally fulfilling and responsible lives. Similarly, science education should enable students to develop the understanding and habits of mind they need to become compassionate human beings able to think for themselves and face life head on (American Association for the Advancement of Science (AAAS), 1990).

Therefore, the goal of learning science can be summed up as scientific literacy (Hurd, 1998; Cobern, 1996; AAAS, 1989; Anderson *et al.*, 1986; Falayajo and Akindehin, 1986; Lederman, 1986; Rowe, 1983). The kind of science education implied in the phrase ‘science for all’ is general and liberal rather than specific and vocational and moves the learner beyond the role of spectator, as often relegated by traditional science education, to a position of active participation.

2.2.1 Scientific literacy

Scientific literacy is the knowledge and understanding of the scientific concepts and processes required for personal decision making, participation in civic and cultural events, and economic productivity (National Academy of Sciences in USA, 1995). Botero (1997) described it as follows:

> *That access to scientific and technological information and understanding has become a fundamental component of citizenship in modern societies. This implies an ability to think critically, solve socio-scientific problems, take part in collective decision-making, and to communicate effectively in a techno-science culture.*

Simply, scientific literacy is the ability of an individual to live satisfactorily and conveniently in the modern society. It is used variously in one or more of the following ways (Norris and Phillips, 2003) (Table 2-1):

Table 2-1: The using ways of scientific literacy.
• Knowledge of the substantive content of science and the ability to distinguish science from non-science (Council of Ministers of Education of Canada (CMEC), 1997; Mayer, 1997; National Research Council in USA (NRC), 1996; Shortland, 1998). • Understanding science and its applications (DeBoer, 2000; Hurd, 1998; Shortland, 1988; Shen, 1975). • Knowledge of what counts as science (DeBoer, 2000; Hurd, 1998; Lee, 1997; Kyle, 1995a; 1995b). • Independence in learning science (Sutman, 1996). • Ability to think scientifically (DeBoer, 2000). • Ability to use science knowledge in problem solving (NRC, 1996; AAAS, 1993; 1989). • Knowledge needed for intelligent participation in science-based social issues (Millar and Osborne, 1998; CMEC, 1997; NRC, 1996). • Understanding the nature of science, including its relationship with culture (DeBoer, 2000; Hanrahan, 1999; Norman, 1998). • Appreciation of and comfort with science, including its wonder and curiosity (Millar and Osborne, 1998; CMEC, 1997; Shamos, 1995; Shen, 1975). • Knowledge of the risks and benefits of science (Shamos, 1995). • Ability to think critically about science and to deal with scientific expertise (Korpan *et al.*, 1997; Shamos, 1995).

From Norris and Phillips, 2003

Miller (1983) integrated more than ten years of relevant literature into a definition of scientific literacy and he proposed a three constitutive dimensions model of scientific literacy, which is:

1. An understanding of the norms and methods of science (i.e. the nature of science);
2. An understanding of key scientific terms and concepts (i.e. science content knowledge); and
3. An awareness and understanding of the impact of science and its applications to society.

Miller's article on a conceptual and empirical review of scientific literacy was influential, so the three dimensions of the definition have formed later the basis of studying ways for measuring scientific literacy. Figure 2-1 attempts to summarise this analysis:

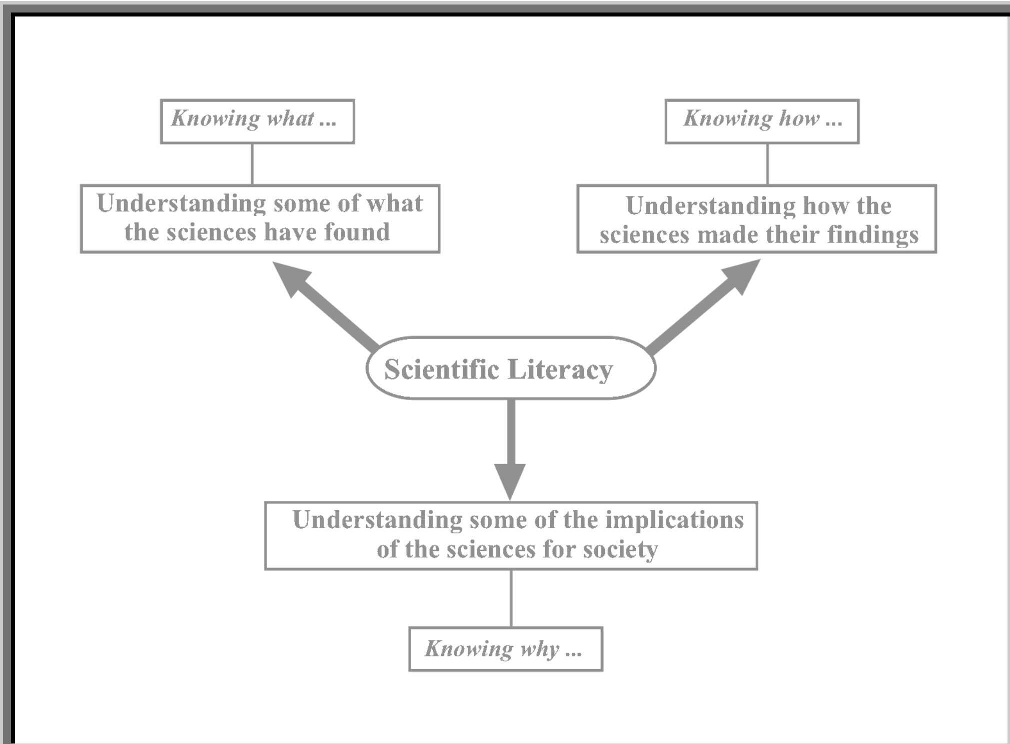


Figure 2-1: Three dimensions of scientific literacy.

In conclusion, scientific literacy requires the individual to understand the meanings, interactions and ramifications of science and society and then to make informed decisions. It means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences, so the person has the ability to describe, explain, and predict natural phenomena (Burkhardt *et al.*, 2000). Scientific literacy entails being able to read about science in the popular press with understanding articles, to think critically when weighing the advantages and disadvantages of the options available, and to engage in social conversation about the validity of the conclusions. Moreover, scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically informed. It also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (Burkhardt *et. al.*, 2000).

2.2.2 Biological literacy

Biology is the branch of science dealing with the study of life. During the past two decades, the knowledge of biology has increased exponentially. We now have a deeper understanding of life on our planet. Also, scientists have tried to apply the knowledge in order to benefit our societies, for example, they mapped the human genome, discovered how to clone animals, and developed new therapies for many diseases, like cancer, immune-deficiency syndrome, Alzheimer's disease, and Parkinson's disease. All these have raised our new hopes.

However, for many people, developments in science are no longer equated with the idea of progress. Concerned about such problems as mad-cow disease and the associated Creutzfeld-Jacob maladies, avian influenza with illness and death in humans, asbestos contamination and its carcinogenic potential, transfusion of contaminated blood, antibiotic loads and hazards of processed food, our societies should attach great importance to biology and biology education (Sadler *et al.*, 2006).

Moreover, several recent developments are controversial and are the subjects of heated public debate, such as stem cell research, genetic engineering, therapeutic cloning, conservation of biodiversity and environmental problems (Sadler *et al.*, 2006). Exclusive technical solutions are neither possible, nor desirable. Citizenship should be dealt with through public debates which help to open the 'black boxes' and illuminate the political, socio-economic and ethical nature of scientific arguments. Citizens need to be 'biologically literate' in order to be able to contribute to decision-making about issues that have a biological dimension, whether these issues are personal or broadly political.

One of the functions of schooling is the development of an informed citizenry, and this is widely assumed to require that all students receive an education in science/biology (Brock, 1996). Biology education is important, but simply improving knowledge about the issues is not the only way in which ideas, problems and questions may be addressed. More important than increasing merely the mass of scientific knowledge is the question of developing and enhancing qualities such as an open mind, critical spirit and self-confidence (Brock, 1996).

In the cause to develop biological literacy among citizens, the aims should be promoted as the following (BioEd, 2004):

- *The ability to read about and understand important issues of the day that are related to biology in any way.*
- *The ability to take an informed interest in media reports about these issues.*
- *The ability to express an opinion about these issues.*
- *An appreciation of the multidisciplinary nature of many of the issues that may have a biological component as well as ethical, economic, political and other dimensions.*
- *An appreciation of biological knowledge that can be helpful to them in the process of democratic decision-making.*

However, school biology is only the beginning of the process of learning to engage with bioscience as an adult. Individuals will continue to learn biology beyond school age, via for example, newspapers, broadcast media, and discussions with related professionals. In addition, the search for scientific information on the internet is becoming increasingly significant (Lee, 1999). It means biological literacy will expand and deepen over a lifetime, not just during the years in school.

From this 'life-long learning' perspective, the goal of school science education is to provide students a basic understanding of the key concepts of science, so that they can develop the confidence to frame questions of science and its applications. Furthermore, it is also important in school science education to promote a positive attitude towards engaging with science by giving students a sense that science is a subject that they are capable of interacting with as adults because attitudes and values established toward science in the early years will shape a person's development of scientific literacy.

2.3 Attitudes to science

As King (1989) noted,

> *As the details of scientific formulae fall away in the months and years after school, it seems likely that the crucial deposits of science and technology education are to do with attitudes, approaches and even values.*

A student's attitudes toward science may well be more important than the knowledge itself, since attitudes determine how he will use his knowledge, whether he will have a desire to study the subject further, and even in taking it for a career. Thus, promoting positive attitudes related to the pupil's understanding in the science is a key part of science education (Johnstone and Reid, 1981). In other words, students should be given opportunities to develop positive attitudes in relation to their studies in the science.

Generally, attitudes are crucial to our everyday lives. Attitudes provide a frame of reference for the individual. They also help us to interpret our surroundings, guide our behaviour in social situations and organise our experiences into a personally meaningful whole. Attitudes allow us to make sense of ourselves and our entire world through which we appreciate the world around us and build social interactions (Reid, 1978). Without attitudes, the world would be a much less predictable place and we would function in it much less effectively.

2.3.1 Definitions of attitude

The term attitude is derived from the Latin word '*aptus*', which is also the root of the word aptitude, and indicates a state of preparedness or adaptation. It is an everyday, common-place word but within a scientific, research context is in need of a more technical and precise definition (Reid, 1978). However, the term attitude is somewhat vague. No one has given a final definition of attitude acceptable to everyone. The various definitions of attitude take on different meanings for different people in different contexts (Johnstone and Reid, 1981) (Table 2-2).

Table 2-2: Differing definitions of the attitude.

Disposition	• *Individual mental processes that determine a person's actual and potential response (Thomas and Znaniecki, 1918).* • *An attitude is a personal inclination, idiosyncratic, present in all individual, directed to objects, events or people, that takes on a different direction and intensity according to the experiences each individual has had (Brito, 1995).*
Learned nature	• *A learned predisposition to think, feel, and behave toward a person (or object) in a particular way (Allport, 1954).* • *A learned predisposition to response in a consistently favourable or unfavourable manner with respect to a given object (Fishbein and Ajzen, 1975)*
Readiness to act	• *An attitude is a mental or neural state of readiness, organized through experience, exerting a directive or dynamic influence upon the individual's response to all objects and situations with which it is related (Allport, 1935).* • *A state of readiness or predisposition to respond in a certain manner when confronted with certain stimuli…attitudes are reinforced by beliefs (the cognitive component), often attract strong feeling (the emotional component) which may lead to particular behavioural intents (the action tendency component) (Oppenheim, 1992).*
Enduring nature	• *A more or less permanently enduring state of readiness of mental organization which predisposes an individual to react in a characteristic way to any object or situation with which it is related (Cantril, 1934).* • *An attitude is a relatively enduring organisation of beliefs around an object or situation predisposing one to respond in some preferential manner (Rokeach, 1968).*
Evaluative nature	• *A concept with an evaluative dimension (Rhine, 1958).* • *A psychological tendency that is expressed by evaluating a certain entity with some degree of favour or disfavour (Chaiken and Eagly, 1993).*

In short, an attitude is defined as an enduring evaluative disposition toward some objects or class of objects in readiness for response and it comprises cognitive, affective, and behavioural components which are usually consistent with each other.

As Oskamp (1991) explained, the idea of readiness for response shows that an attitude is not behaviour, not something that a person does; rather it is a preparation for behaviour, a predisposition to response in a particular way to the attitude object and mainly has been learned from experiences. An attitude towards an attitude object will not take place until evaluation has been done, so people respond to the object with evaluation which may express approval or disapproval, favour or disfavour, liking or disliking, approach or avoidance, attraction or aversion, or similar reactions.

The term attitude object can be everything that becomes an object of thought. It is used to include things, people, places, ideas, actions, situations, events, or concepts. In science education, Gardner (1975) subdivided attitude object into two major categories:

- *Attitudes to science: for which there is always some distinct attitude objects (e.g. important, enjoyment, etc.).*
- *Science attitudes: styles which the scientist is presumed to display (e.g. honesty, open-mindedness, etc.).*

Reid (2006) has demonstrated that attitudes towards science have been a persistent concern in science education for more than forty years. He argued that four broad areas of targets can be identified (Figure 2-1):

1. Attitudes towards the science subject itself;
2. Attitudes towards the learning of science subject (process of learning);
3. Attitudes towards the process of science (the so-called scientific attitudes); and
4. Attitudes towards themes/topics/issues arising in the study of a science subject.

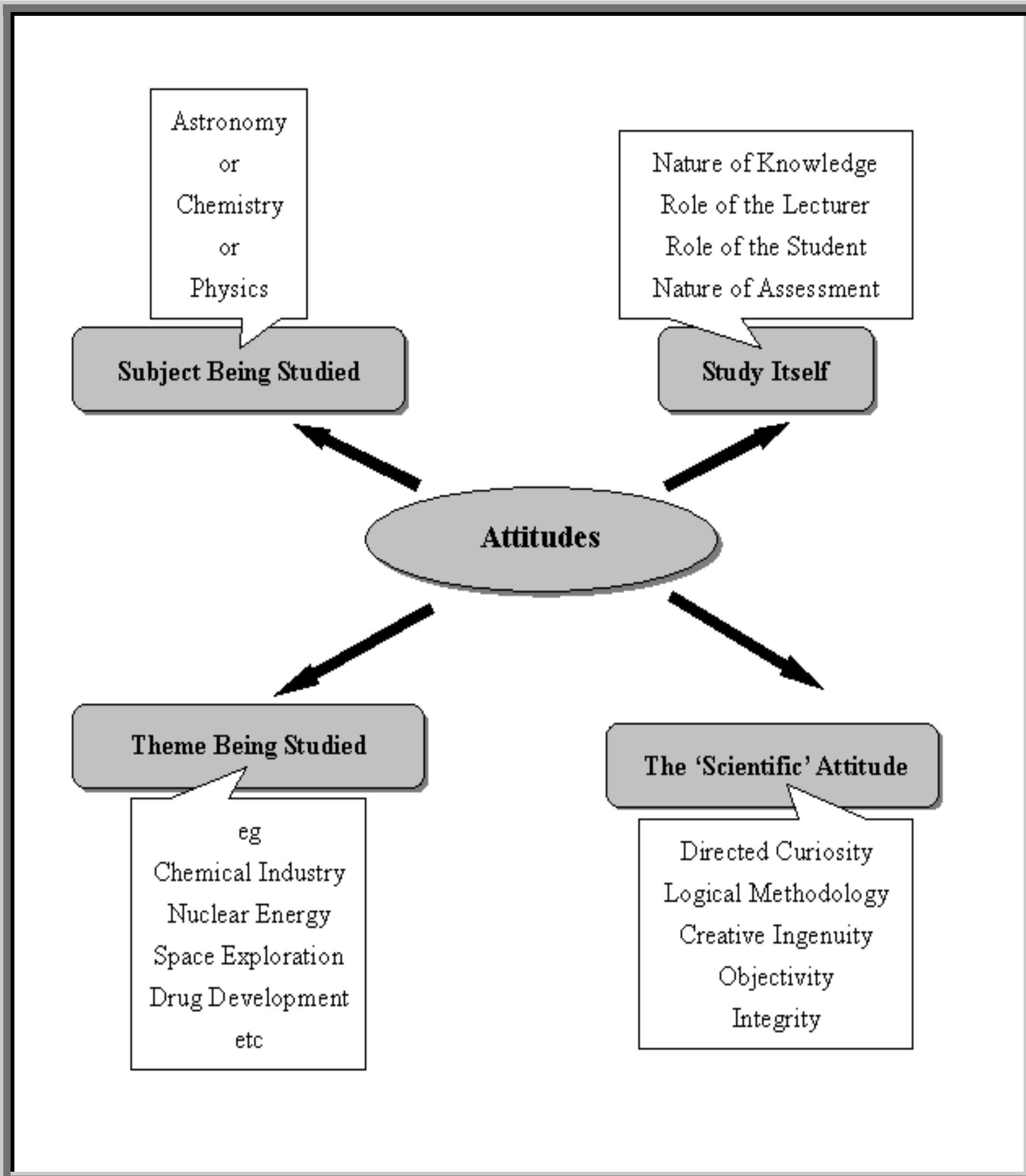


Figure 2-2: Four areas of attitudes in science education.

From Reid, 2004

Considerable research has been focused on how to encourage positive attitudes towards the science subject by choosing the curriculum contents and teaching ways appropriately (Krogh and Thomson, 2005; Pell and Jarvis, 2004; 2001; Reid and Skryabina, 2002a; b; Osborne *et al*., 2003; 1998; Ramsden, 1998). People's knowledge, feelings, and experiences may lead to evaluations and this may lead to subsequent decisions. Without interest or motivation in the subject being studied, it is very hard for the learner to keep learning.

In order to be effective in learning in science, students need to develop attitudes not only towards the learning of science, such as understanding about the nature of knowledge, about approaches to successful study, about the nature of learning as a life-long process and so on, but also towards the process of science. This is associated with scientific methods, skills related to the undertaking of experimental work, and other more general dispositions toward the beliefs and procedures of science (Ramsden, 1998), such as curiosity, open-mindedness, critical-mindedness, creative ingenuity, objectivity, caution in drawing conclusions, weighing evidence, loyalty to the truth, and existence of cause and effect relationships (Reid and Serumola, 2006; Byrne and Johnstone, 1987). However, there are still some problems among educators and related researchers in establishing an agreement of what constitutes the scientific attitude and uncertainties about whether this is really an attitude or a method of working (Reid, 2006).

On the other hand, literature is replete with practical suggestions and skills deemed necessary to be included in school curriculum (Hurd, 1998; AAAS, 1989; Aikenhead, 1986; Falayajo and Aikenhead, 1986; Rubba and Anderson; 1978). Studying topics which involve contemporary issues in science like pollution and genetic engineering will provide students with opportunity to develop attitudes towards these and related themes. This is known as Science-Technology-Society (STS) approach (which will be discussed in the next section). For example, if students learn more about chemical industry, they will develop attitudes towards aspects of the work of chemical industry; if students understand more about genetics, their attitudes towards aspects of genetic engineering will be deepened (Jung, 2005).

2.3.2 Attitudes formation and analyses

As mentioned in the definition of the attitude, evaluation plays a key role in the attitude formation. Most agreed that a complete description of the attitude requires all three components (McGuire, 1985; Ajzen and Fishbein, 1980; Bagozzi and Burnkrant, 1979; Reid, 1978). These have been termed the A-B-Cs of attitudes: the affective, behavioural, and cognitive component.

An attitude can be formed through affective, behavioural, and cognitive processes, each of which could operate on its own or in combination (Zanna and Rempel, 1988).

Moreover, each of the three components of an attitude consists of a different way that an individual can react to some subjects. These three components are consistent with each other and also can affect each other (Fishbein and Ajzen, 1974).

In addition, it deserves to be mentioned that attitudes cannot be directly measured because of their latent construct nature. Attitudes are considered as one of the numerous mental states that psychologists have constructed to explain the responses observed under certain stimuli. Thus, all attitudes must be inferred by considering the observed stimuli and the observed evaluative responses (Figure 2-3). Social psychologists assume that the responses that reflect real people's attitudes can also be divided into three categories: affective, behavioural, and cognitive responses. There is not necessarily a precise relationship between attitude formation and attitude expression (Chaiken and Eagly, 1993).

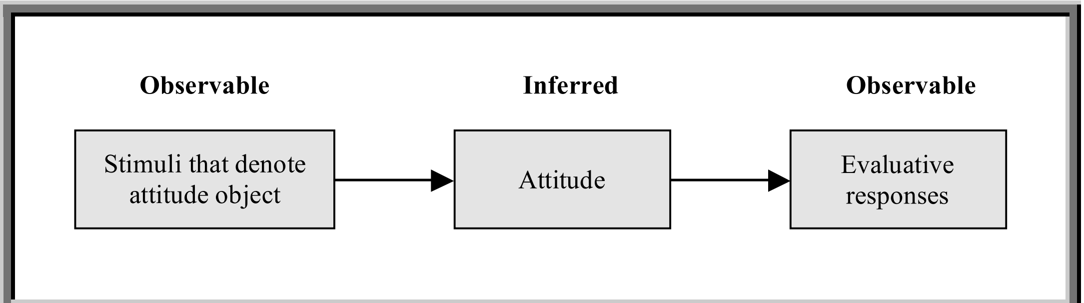


Figure 2-3: The general way of attitudes investigation.

From Chaiken and Eagly, 1993

The A-B-Cs of attitudes are:

'A': The affective component. This refers to the feelings and emotions toward the object. Affective processes can take place when the person experiences feelings, moods, or emotions like anger, wanting, and happiness etc. It is essentially the evaluative element in an attitude, on the basis of which the attitude holder judges the object to be good or bad. In general, a person who evaluates an object favourably is likely to experience positive affective reactions towards it, whereas a person who evaluates an object unfavourably is likely to experience negative affective reactions towards it (Chaiken and Eagly, 1993). For example, I like biology because it is fun and I do not like mathematics because it is boring.

'B': The behavioural component. It represents an intentional or action element in attitudes. It is also called conative or action tendency component (Bagozzi, 1978). While the evaluation about an attitude object builds on the basis of past behaviour, behaviour could be considered as forming of attitude (Bem, 1972). For example, if a pupil has positive experience related to one activity, he/she will tend to engage in behaviour that fosters or supports it, or have intentions to act like that.

'C': The cognitive component. It is consisting of any bit of information knowledge or beliefs relevant to the attitudinal object. A person obtains information about an attitude object and then beliefs are developed. The cognitive way of attitude formation can be obtained through a direct experience (e.g. science class) or indirect experience (e.g. TV programmes or peer group). In general, a person who evaluates an object favourably is more likely to associate it with positive attributes, whereas a person who evaluates an object unfavourably is likely to associate it with negative attributes (Chaiken and Eagly, 1993). For example, a pupil who likes genetics may say it is useful to learn about biotechnology and its applications in our daily life and a pupil who does not like physics may say it is too mathematical or is not really useful in the life.

In short, attitudes to a concept such as science are the person's collections of beliefs and knowledge of what science actually involves, and episodes that are associated with it, which are linked with emotional reactions and past behaviour. The stimulation of these reactions affects decisions to engage in behaviour, such as choosing to take a science course, to read about scientific matters, or to adopt a science-related hobby. It is important to notice that children have developed some kinds of attitudes about science before they start formal education in school (Reid, 2006).

2.3.3 Factors in developing attitudes

A person's attitudes towards science can be seen as a learned disposition to evaluate in certain ways objects, people, situations, or concepts involved in the learning science (Gardner, 1975). That attitudes are learned is generally agreed but many factors can operate in the acquisition process. The key circumstance for attitude formation is that the person expects to interact with the object and needs to be prepared for that interaction (Gerard and Orive, 1987). Jamieson and Zanna (1988) described it as 'needs for the cognitive structure'. It means when a person expects to interact soon with an object, the person feels an opinion-forming imperative, which motivates him/her to form a relatively clear-cut stance towards the object.

Attitude formation refers to the initial change from having no attitude toward a given object to have some attitude toward it; from no experience about it to have thought on the basis of evaluation, either positive, negative, or in between. Determining factors which cause a person to acquire a particular attitude toward an object can be divided into internal and personal determinants and external influences (Oskamp, 1991; Khan and Weiss, 1973).

1. Internal and personal determinants:
   - Genetic and physiological factors;
   - Direct personal experience.

2. External influences:
   - Parental influence;
   - School teaching;
   - Peer groups;
   - Mass media.

These two groupings do correlate with each other and affect each other (Chaiken and Eagly, 1993). Some internal variables (e.g. personal experience) may be the result of external variables. Some internal variables may interact with external variables in producing their effects, like certain behaviour of parents may exert varying effects upon children of differing personalities. Moreover, internal perceptions of external variables may be different from external variables that result in formation of unexpected attitudes. For example, a person's attitudes may be influenced by his/her beliefs about his/her parents' attitudes and these beliefs may be unrelated to the attitudes his/her parents actually hold (Gardner, 1975).

Genetic and physiological factors, such as personality, gender, age, and illness, may generate a predisposition for the development of particular attitudes. The research of Hutching (1967), working with students of arts and science, found that pupils who like doing science are more realistic, self-reliant, and like logical evidence. Boys are more positive towards science than girls (Bradley and Hutchings, 1973). Moreover, it has been supported through many studies that attitudes towards science decline over the years of secondary schooling, particularly for girls (Ramsden, 1998). However, Reid and Skryabina (2002a; b) did not find the same pattern in Scottish schools. Here, girls were very positive towards their study in physics. It may be due to interaction of external influences, like the nature of classroom instruction and the relationships among people in classrooms.

Apart from these innate and physical factors, the earliest and most fundamental way in which people form attitudes is through direct experiences with the attitude object. This continues throughout a person's entire life. Generally attitudes from one's direct experiences are stronger than those formed through indirect or vicarious experiences (Fazio, 1988). Repeated exposure to the stimulus object also enhances a person's attitudes about the object (Zajonc, 1968).

Indeed, a child's attitude is largely shaped by its own experiences with the world, but much of these experiences comprise explicit teaching in schools and implicit modelling of parental attitudes. Parental influence over a young child's behaviours and attitudes is very great because parents have almost totally control over the young child's information input, the behaviours demanded of the child, and the rewards and punishments meted out (Chassin *et al.*, 1984; Hoffman, 1977).

Learning at school has had enormous influences in determining pupils' attitudes. Many studies had showed the importance of school influence (Reid and Skryabina, 2002a; Devin and Williams, 1992; Germann, 1988). Pupils interpret the things that their teacher taught, and the experience the teacher arranges for them, in terms of these early experiences and beliefs, generally in such a way as to support the views already formed. Thus, the manner in which the subject is taught, in which the curriculum is presented, and in which instructions are conducted is the result of the knowledge, world-views, beliefs, skills, and attitudes that the teacher brought to the classroom.

From the end of first school onward, peer-group contacts become increasingly significant and time-consuming (Renshon, 1977). Where peer-group norms agree with parental or school standards, previously existing attitudes and value may be strengthened (Youniss, 1980).

The investigation of Comstock *et al.* (1978) showed that most people rely on mass media for most of their daily information. However, the media do not simply transmit information. By selecting, emphasizing, and interpreting particular events, and by publicizing people's reactions to those events, they help to structure the nature of 'reality' and to define the crucial issues of the day, which in turn impels the public to form attitudes on these issues (Kinder and Sears, 1985; Roberts and Maccoby, 1985; Zuckerman *et al.*, 1980).

Students come to school with some existing attitudes and evaluations toward a subject like science. They will then experience feelings about the subject and the teacher and they will gain knowledge and experiences. Alongside that, there will be beliefs or opinions from parents, peer-group, and mass media influences related to the subject. All of these influences and experiences will come together to bring about attitudes towards science, its learning and towards topics covered in the course. The generation of positive attitudes is a critical aim for teachers and curriculum planners, for without such attitudes, learning will be hindered and attitudes taken on into life may well be unhelpful.

2.4 Approaches of science education

From the historical events, social forces led the nature of science to transform into the institutionalisation (the 'basic' or 'pure' science), professionalisation (applied science for preparing one for scientific community), and socialization (science for all; preparing one for citizenship) of fundamental characteristics (Elkana and Mendelsohn, 1981; Mendelsohn, 1976). In recent times, science educators and researchers have witnessed the emergence of substantial social forces to science education in many of countries. According to Solomon and Aikenhead (1994), there is:

- *A pervasive decline in the interest and understanding of science;*
- *An awakening recognition of science as a human, social, and technological endeavour;*
- *An egalitarian movement in public education; and*
- *A proposal to synthesize science and technology education.*

Thus, several serious attempts have been made to modify the school science curriculum in many countries. When designing a new curriculum, countries share a common trend towards teaching science embedded in technological and social contexts familiar to students (Fensham, 1992; Eijkelhof and Kortland, 1988; Hofstein *et. al.*, 1988; Bybee, 1985; National Science Teachers Association in USA (NSTA), 1982). This new curriculum movement advocates teaching science in a STS approach.

2.4.1 Purposes of Science-Technology-Society (STS) approach

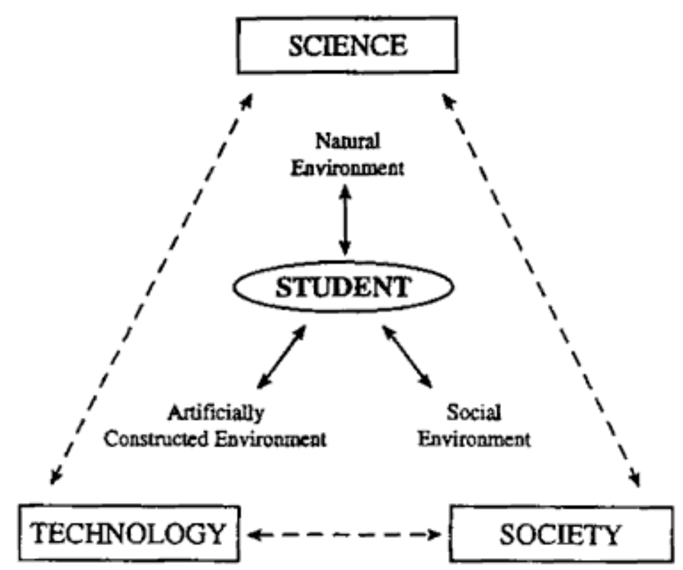


Figure 2-4: An essence of the STS education.

From Solomon and Aikenhead, 1994

The STS approach emerged primarily as a result of social forces and is therefore seen as reform in science education. Fundamentally, the STS science teaching is student-oriented (Figure 2-3), as contrasted with the scientist orientation of tradition science teaching (Solomon and Aikenhead, 1994).

Students strive to understand their everyday experiences and the environment around them. Teaching science through an STS approach refers to teaching about natural phenomena that embeds science in the technological and social environments of the student. In other words, the STS instruction aims to help students make sense out of their life today and for the future, and does so in ways that support students' natural tendency to integrate their personal understanding of their social, technological and natural environments.

The STS science education has to bring a balance between three general purposes. Each purpose has a different emphasis in order to develop students' attitudes towards science and scientific literacy. These purposes have also guided curriculum development in the STS science, which can be summarised (Solomon, 1993; Cheek, 1992; Yager, 1992a; b; Hart, 1989; Fensham 1988; Aikenhead, 1986; Bybee, 1985):

1. Acquisition of knowledge and increase of interest (concepts within, science and technology and interactions among science, technology and society) for personal matters, civic concerns, or cultural perspectives.

2. Development of learning skills (processes of scientific and technological inquiry) for information gathering, critical thinking, logical reasoning, problem solving, and decision making.

3. Development of values and ideas (dealing with the interactions among science, technology, and society) for local issues, public policies, and global problems.

One of the features of the traditional science curriculum has been to prepare students for the next level of education and to teach them knowledge of science (Roberts, 1988). These functions are not ignored in the STS education, but they are not given as strong an emphasis. Therefore, an STS science curriculum addresses the needs of two groups: one is the future scientists and technologists (the elite), and the other is the future citizens who need intellectual empowerment to participate thoughtfully in their society (the attentive public; science for all).

2.4.2 STS curriculum

Science education using the STS approach can offer an interdisciplinary knowledge to handle the shift of researchers in the sciences from being single disciplined to inter- or multidisciplinary (Holbrook, 1992). It, therefore, breaks down the discipline boundaries as well as provides a context for science education. Yager (1992a) argued that:

> *There are no concepts and/or processes unique to STS: instead, STS provides a setting and a reason for considering basic science and technology concepts and processes. STS means determining and experiencing ways that these basic ideas and skills can be observed in society. STS means focusing on real-world problems which have science and technology components from students' perspectives, instead of starting with basic concepts and processes.*

In general, the STS curriculum has both lesson content and teaching methods (Aikenhead, 1992). The methods are supportive of constructivist strategies, rather than being transmissive (Pederson, 1992). These incorporate cooperative learning, peer support, issue based techniques, and connected knowledge by using simulations, small group work, group discussions, debates, problem solving, decision making, role playing, divergent thinking, or using the media and other community resources. (Solomon, 1993; 1989; Aikenhead, 1988; Byrne and Johnstone, 1988). It encourages participation by students, enhances student motivation and attitude development, and, therefore, achievement (Byrne and Johnstone, 1988).

Interactive learning approaches are often identified as being essential to the STS science instruction (Solomon, 1993; 1987): making the concrete connections between the academic science content and the student's everyday world. The research evidence of Byrne and Johnstone (1988) showed that, in terms of learning science knowledge, interactive educational games can be just as effective as traditional teaching ways. In terms of developing positive attitudes about science, interactive games can be far more effective than traditional teaching ways. Moreover, the strategies of role playing, small group discussion and decision making can stimulate thought and interest and then develop greater commitment to their life and the society in which they live.

Regarding the contents of the STS education, Aikenhead (1986) suggested the contents to include the following:

1. *Social issues internal to the scientific community (epistemology, history, and sociology of science, etc.);*
2. *Social aspects external to the scientific community (socioscientific problems, e.g. overpopulation, nuclear reaction, etc.); and*
3. *Science discipline content (biology, chemistry, physics, and earth science).*

These three aspects are to be integrated in a science classroom in different ways and to different degrees by the science teacher. Aikenhead (1986) proposed the structure of the STS science education (Table 2-3). It delineates the diversity in the STS science in terms of the degree and manner in which the STS content is integrated with traditional science content.

Table 2-3: Categories of the STS Science.

(1) Motivation by the STS content:	
Traditional school science, plus a mention of the STS content in order to make a lesson more interesting. (The low status given to the STS content explains why this category is not normally taken seriously as the STS instruction).	Students are not assessed on the STS content.
(2) Casual infusion of the STS content:	
Traditional school science, plus a short study (about 1/2 to 2 hours in length) of the STS content attached onto the science topic. The STS content does not follow cohesive themes.	Students are assessed mostly on pure science content and usually only superficially (such as memory work) on the STS content (for instance, 5% STS and 95% science).
(3) Purposeful infusion of the STS content:	
Traditional school science, plus a series of short studies (about 1/2 to 2 hours in length) of the STS content integrated into science topics, in order to systematically explore the STS content. This content forms cohesive themes.	Students are assessed to some degree on their understanding of the STS content (for instance, 10% STS and 90% science).

Continued

Table 2-3: Categories of the STS Science.

(4)	**Singular discipline through the STS content:**	
	The STS content serves as an organizer for the science content and its sequence. The science content is selected from one science discipline. A listing of pure science topics looks quite similar to a category (3) science course, though the sequence would be quite different.	Students are assessed on their understanding of the STS content, but not nearly as extensively as they are on the pure science content (for instance, 20% STS and 80% science).
(5)	**Science through the STS content:**	
	The STS content serves as an organizer for the science content and its sequence. The science content is multidisciplinary, as dictated by the STS content. A listing of pure science topics looks like a selection of important science topics from a variety of traditional school science courses.	Students are assessed on their understanding of the STS content, but not as extensively as they are on the pure science content (for instance, 30% STS and 70% science).
(6)	**Science along with the STS content:**	
	The STS content is the focus of instruction. Relevant science content enriches this learning.	Students are assessed about equally on the STS and pure science content.
(7)	**Infusion of science into the STS content:**	
	The STS content is the focus of instruction. Relevant science content is mentioned, but not systematically taught. Emphasis may be given to broad scientific principles. (The materials classified as category (7) could be infused into a standard school science course, yielding a category (3) STS science course.)	Students are primarily assessed on the STS content, and only partially on pure science content (for instance, 80% STS and 20% science).
(8)	**The STS content:**	
	A major technology or social issue is studied. Science content is mentioned but only to indicate an existing link to science. (The materials classified as category (8) could be infused into a standard school science course, yielding a category (3) STS science course.)	Students are not assessed on pure science content to any appreciable degree.

From Solomon and Aikenhead, 1994

The STS instruction can help students understanding of the STS content (the STS interactions, the nature of science and technology, and the social issues within and outside the scientific enterprise), thinking skills, and attitudes toward science. Mbajiorgu and Ali, (2003) claimed that good STS science education is relevant, challenging, realistic, and rigorous. It is believed that the STS approach in addition to increasing scientific literacy will also increase positive attitudes and achievement in the science (Mbajiorgu and Ali, 2003). However, some in the field of researchers in science education look with misgiving and support further research.

2.5 Conclusions

Attitudes are the core of human individuality. The brave protests at Tiananmen Square in China testify to how individuals hold their attitudes.

In our everyday lives, people love and hate, like and dislike, favour and oppose. They agree, disagree, argue, and even convince each other. Attitudes contribute to a person's psychological make-up. Every day, each of us is exposed to countless attempts at changing or reinforcing our attitudes through communications, the mass media or the internet. Moreover, when individual attitudes turn into public opinions, then these attitudes determine the social, political and cultural climate in a society, which in turn affects the individual life of the people in that society (Bohner and Wanke, 2004).

At school, a student's attitudes guide his perceptions, feelings, and behaviour to a subject, which of course influence learning. Attitudes may influence the attention to the class, motivation of learning, the use of categories for encoding information and the interpretation, judgment and recall of attitude-relevant information. Accordingly, attitude is a determinant and a consequence of learning (Reid and Skryabina, 2002a). The quality of learning is also affected by attitudes (Reid, 2006).

In addition, because positive attitudes encourage students to interact with science material, they may well be better equipped to engage with social issues related to the science. This implies an ability or intent to think critically, to take part in collective decision-making of socio-scientific problems, to communicate effectively in a techno-science culture, and to expand and continue learning in the whole life. It means to reach scientific literacy; one of the necessary skills for 21st century citizens. It is also one of aims of science education.

However, scientific literacy is based on the knowledge and understanding of scientific concepts and process. The next chapter of our study will focus on one of the science subjects, biology, to probe into the difficulties in learning biology, especially in genetics.

Chapter Three

Difficulties in Learning Biology/Genetics

3.1 Introduction

Science is a way of knowing, discovering and understanding (Abell, 1994). Science concerns itself with questions which can be answered by reproducible measurements or abilities to ask questions and to get answers which can be interpreted and built up into a corpus of meaningful knowledge. Hence we do science to make sense of our surroundings.

Since the 1980's there has been growing concern about scientific literacy as a high priority for all citizens helping them to be interested in and understand the world around them, to engage in the discourses of and about science, to be sceptical and question of claims made by others about scientific matters, and to make informed decisions about the environment and their own health and well-being.

However, the fact is that many students claim that science is hard to learn (Johnstone, 1991) and the understanding of scientific ideas of the majority of students is thought to be very poor (Gott and Johnstone, 1999). Indeed, there are many common and persistent misconceptions of basic science ideas (Millar, 1996). During the last few decades, there have been numerous studies in the science education literature about school and university students' difficulties and understanding in learning science and which vary from the simplistically obvious to the more deeply complex bearing some philosophical connotations.

The difficulties and problems of learning science experienced by students can be attributed to a variety of reasons (Selepeng, 2000; 1995; Gray, 1997; MacGuire and Johnstone, 1987; Cassels and Johnstone, 1983):

- Low student aptitudes/ability;
- Ingrained misconceptions;
- The essence of scientific knowledge;
- The abstract nature of science concepts;
- Cognitively ill-equipped for abstract ideas;
- The complexity of the language of science;
- Too large an amount of content presented to the learners;
- Mathematical content; and
- Negativity in attitudes students have for the subject.

Narrowing the field of focus from the whole of science to just biology, there are reasons to feel optimistic. Firstly, the absolute numbers of students doing biology at advanced level have continued to increase in many countries, like England and Wales. It is unlike the situation in physics and chemistry (Reiss, 1998). In Scotland, numbers of students taking biology have grown enormously over the years but physics and chemistry are not declining. In fact, the three science subjects are the most popular of all elective subjects at higher grade (university entrance examinations) (Scottish Qualifications Authority (SQA), 1997-2006).

Secondly, pupils generally described themselves as being more interested in biology than in physics or chemistry (Jarman and McAleese, 1996). Moreover, we live in an age where biology seems to be in the ascendancy. This is evident in many of world's burning issues (Reiss, 1998), such as biodiversity, human population growth, genetically modified organisms, reproductive technologies, and prolongation of life. Finally, most students assumed that biology is easier than the other science subjects (National Science Board of USA, 2002).

However, although the number of students taking biology continues to increase, biology entries are decreasing (though considerablly less severe ones than in chemistry, physics and mathematics and certain other subjects) (Science and Technology Committee Report of Science Education of England and Wales, 2002). Additionally, research in America had shown that the performances of biology in school are decreasing and the general levels of understanding of biological concepts may be insufficient for the average citizen to be able to make informed decisions (National Science Board of USA, 2002). Furthermore, even though pupils thought biology is an easier and more interesting science subject, it still has some characteristics the same as other science subjects and these identities cause difficulties and problems in learning.

This chapter and the next chapter are going to review the learning difficulties in biology/genetics (Chapter three) and the individual developmental nature and cognitive nature of the learning process (Chapter four).

3.2 Topics of high perceived difficulty in school biology

More than 25 years ago, several studies were published about the learning difficulties in biology (e.g. Johnstone and Mahmoud, 1980; Johnstone and Mughol, 1976; Johnstone, 1974). A list of topics of biology was compiled from the published syllabuses of the Scottish Examination Board at Standard Grade (approximately junior high school level) and at Higher Grade (university entrance level) (Table 3-1). This list which comprised 36 topic headings was derived from the most commonly used textbooks.

Table 3-1: The list of biology topics.

• Active transport and secretion materials	• Genetic control of development and metabolic processes
• Diffusion and osmosis	• Hormonal influences in animals and plants
• ATP and chemistry of respiration	• Feeding and digestion
• Absorption of light by photosynthetic pigments	• Excretion and the role of the kidney
• Chemistry of photosynthesis	• Skeleton, muscle and movement
• Sexual and asexual reproduction in plants	• Heart, blood and blood circulation in mammals
• Developing eggs of fish and mammals	• Mammalian lung and breathing
• Growth differences between plants and animals	• Central nervous system, sense organs and coordination
• DNA and RNA (structure and function)	• Physiological homeostasis
• Cellular response in defence (immune system)	• Maintaining a water balance in animals and plants
• Mitosis	• Population dynamics
• Meiosis	• Food and energy chain in ecosystem and pollution
• Gametes, alleles, and genes	• Obtaining food in animals and plants
• Monohybrid and dihybrid crosses and linkages	• Behavioural responses of animals to danger
• Genetic engineering	• Defence mechanisms in plants
• Mutation	• Antibiotics and biological detergents
• Natural selection, specification and adaptive radiation	• Fermentation of yeast and baking and brewing
• Enzymes	
• Aerobic and anaerobic respiration	

From Bahar *et al*., 1999a

Johnstone and Mahmoud (1980), Steward (1982a) and Finely *et al.* (1982) mentioned that several biological topics were identified by their level of difficulty in terms of instruction by teachers, as well as the difficulty which students have in learning these topics. These are:

- Water transport in organisms including osmosis, water potential, and water balance;
- Energy storage and conversions in photosynthesis, respiration, ATP and ADP;
- Mitosis and meiosis;
- Enzymes structure and function;
- The chromosome theory of heredity;
- Mendel's laws of genetics; and
- Mechanism of evolution.

15 years later, research in Scotland revisited this area to check what changes in students and teachers perceptions were apparent (Bahar *et al.*, 1999a). The results showed that five of the six topics which were recorded as difficult were from the field of genetics. They are meiosis, gametes, alleles, and genes and genetic engineering, along with monohybrid and dihybrid crosses and linkages. It indicated that the general area of genetics is still posing problems. The importance is that this is not just the opinions of students, but also supported by the experienced teachers and the national examiners of countries (Bahar *et al.*, 1999a; Finley *et al.*, 1982).

Mach science education literature of the past two decades has dealt with learning and teaching genetics. Findings showed a poor understanding of the processes by which genetics information is transferred, a lack of basic knowledge about the structure involved (e.g. gene, chromosome, cell), and there appeared to be widespread uncertainty and confusion among students of various levels and among the population in general (Marbach-Ad, 2001; Lewis and Wood-Robinson, 2000; Lewis *et al.*, 2000a; b; c; Marbach-Ad and Stavy, 2000; Wood-Robinson, 2000; Lock *et al.*, 1995; Wood-Robinson, 1994; Kindfield, 1991; Longden, 1982).

Knippels *et al*. (2000) had interviewed biology teachers and ten meaningful problem categories were extracted (Table 3-2).

Table 3-2: The main problems in learning and teaching genetics.

Category	Description
(1) Abstract nature	Alienation from real biological phenomena due to lack of connection between inheritance and sexual reproduction in general, and meiosis in particular.
(2) Complexity	Inheritance has to do with all levels of biological organisation and an adequate understanding of genetics require 'to-and-fro' thinking between molecular, cellular, organism, and population level. Simplification of inheritance easily leads to conceptual problems.
(3) Probabilistic reasoning	Students who perform poorly in mathematics often also do so when solving genetic problems; see also differences between students (10).
(4) Image	Inheritance may be perceived as a difficult topic in biology, resulting in poor motivation or a tendency to give up.
(5) Examinations	Mendelian genetics is just a small part of the final exam; consequently not much time is allotted to this difficult subject, although spending some extra time would be advantageous. Current practice is to teach and learn 'tricks' instead of insightful problem-solving behaviour.
(6) Terminology	Genetics is rich in terminology, but not all terms are necessary for adequate understanding. Furthermore, students are unwilling to memorise relevant terms; see also image (4). In addition, teachers and authors of curriculum materials do not always use terms consistently and explicitly. Inadequate translation of terms from English into other language can also result in misunderstanding.
(7) Pedigrees, Punnett Square diagrams and symbolising	Students face problems in representing and reading genetics knowledge in schemes and symbolising and symbols. These problems may increase in connection with the abstract nature of genetics (1) and its richness in terminology (6).
(8) Problem-solving	Students not only have difficulties with the representation of problems (7), but they also lack problem-solving and reading skill.
(9) Cell division	Students have an inadequate understanding of the process of meiosis, and do not always understand the differences between mitosis and meiosis. Consequently, students acquire a poor conceptual basis of genetics.
(10) Differences between students	Relevant prior knowledge and cognitive maturity is required for an adequate understanding of genetics. Students may differ in these respects; see also image (4). Furthermore, differences may also be related to chemistry and mathematics courses.

From Knippels *et al*., 2005

In order to reach students' acquisition of meaningful understanding of genetics, suggestions have been advanced for dealing with problems of preconceptions (Wood-Robinson, 1994), terminological language, basic mathematical requirements (Lewis *et al*., 2000a; Longden, 1982), and of spatial and conceptual issues involved in segregation of alleles and chromosome behaviour in cell divisions (Pashley, 1994a; b; Brown, 1990).

Moreover, significant changes should be made in both curriculum planning and sequencing of teaching when genetics is taught at the school level (Knippels *et al*., 2000).

3.3 Nature of scientific knowledge

Biology is one of the most dynamic research disciplines within the natural sciences. New research discoveries are published almost daily as research papers in scientific journals (Brill *et al*., 2003). Many of them quickly reach the mass media and subsequently influence our everyday lives. In time, the quantity of biological knowledge that people should update increases and also the gap between the accumulated knowledge in biology and the knowledge that is taught in schools increases (Brill *et al*., 2003). As Ravetz (1997) mentioned:

> *The course of science as revealed by historians and philosophers is far from a steady accumulation of facts, punctuated by the occasional revolution among theories. Indeed, much of the development of the most basic sciences in this century has involved grappling with the unsolved problems and paradoxes at their foundations.*

On the other hand, Durkhein (1994) noted that:

> *Truth cannot be immutable because reality itself is not immutable; hence truth changes in time and truth cannot be one because this oneness would be incompatible with the diversity of minds; hence truth changes in spaces.*

In essence, the change in scientific knowledge has always existed and will continue to occur as a result of the developments that the way things are viewed at present might change to accommodate new ways of reasoning. For instance, Darwin's theory evolution has been subject to continue revision and adjustments with a lively ongoing debate (Ravetz, 1997). These adjustments and re-examinations to this theory and many other theories need be made to suit newly evident circumstances.

Besides, with the construction of a body of knowledge aimed at explaining what is 'really' going on in the world both within and around us, by different people all over the world, there have always been debates on the validity of explanations. This controversial and conflicting nature sometimes makes it difficult to handle in classroom situations, for both teachers and students.

In sum, the nature of science knowledge is multifaceted and an important component of scientific literacy (Meichtry, 1993). Selepeng (2000) noted, *science has been characterised as social, cultural, personal, and contextual versus external and 'out there'; simple and straight-forward versus complex and abstract; coherent and unproblematic versus fragmented and chaotic; limited in its ability to provide answers versus the only answer to every problem; absolute versus debatable; continuously changing versus steady and constant; and speculative versus true and real*. These make science even more interesting and yet intimidating.

3.4 Common misconceptions in biology/genetics

From birth, the infant knows nothing of science, and so has no ideas or attitudes to it. An early acquisition might be an image obtained from a picture book, or an idea picked out from stories or a conversation between parents. The most likely source these days is television, where it is a matter of chance whether a right or wrong, positive or negative view of science is observed (White, 1988). Another source is the real world, where the child's experiences are often interpreted for him/her by adults. However, they are sometimes in conflict with accepted scientific ideas (Alparslan *et al.*, 2003).

Children try to make sense of the world around them, by assimilating their observations and experiences into their own meanings and explanations (Johnstone, 1991). Everyday evidence of biology is commonplace and can be experienced by most young people from an early age. Discussions with relatives and with peers may often centre on this evidence, and thus some knowledge of biology is likely to be possessed by most children by a relatively early age (Ramorogo and Wood-Robinson, 1995). Again many of these ideas may be different to those generally accepted by scientists.

Several investigators (Wood-Robinson, 1994; Karbo *et al.*, 1980) had shown that young people use their own intuitive ideas to explain some aspects of inheritance, even before they receive tuition on these subjects. By the time a child receives formal science education, his/her preconceptions are already well established working theories, and problems arise when these ‘naive’ theories disagree with the presented science concepts in the classroom. These preconceptions then interfere with new learning and lead to the establishment of *misconceptions* or *alternative conceptions* (Driver and Oldham, 1986; Arnaudin and Mintzes, 1985; Fisher, 1985). These can be very stable and highly resistant to change (Driver and Bell, 1986). Obviously, these ideas should be taken into account by teachers when planning and teaching; if they are not, and if they are erroneous, they can easily interfere with the acquisition of scientifically acceptable knowledge about genetics (Wood-Robinson, 1994).

On the other hand, many misconceptions are formed in the way unscientific everyday language used. Confusion is caused between the everyday uses and scientific meanings of words, for example: alive and animal leading to the idea that inanimate objects which ‘move’ are alive and that animals are large land mammals or pets (Bell and Freyberg, 1985; Simpson and Arnold, 1982; Tamir *et al.*, 1980). Also Seymure and Longden (1991) proposed that misconceptions such as respiration is the same as breathing, and that respiration occurs in the lungs, are already implemented in the minds of the students and are resistant to change over time. Class inclusion is another problem: the idea that an insect is an animal and that grass, trees and flowers are plants are difficult for pupils to grasp (Bell and Freyberg, 1985; Freyberg, 1985; Ryman, 1974). Students’ ideas concerning evolution may be either naturalistic, because they are aware of their own needs and desires, or they believe that repeated use induces changes which can be inherited (Deadman and Kelly, 1978).

Other misconceptions can arise if the topic is completely new to the child because there are no prerequisite ideas to build upon, or if the cognitive demand of the topic is greater than the conceptual development of the child. Many scientific concepts require abstract thinking (Lawson and Renner, 1975). Examples are such as photosynthesis, respiration, enzyme, mitosis and meiosis, gametes, alleles, and genes and genetic engineering. They claim students’ ability to deal with abstract concepts in meaningful learning is correlated with their level of cognitive development as defined by Inhelder and Piaget (1958) (see Chapter four).

In relation to this view, Lawson and Renner (1975) reported that, unless the pupils have reached the Piagetian level of formal operational thinking, they will not be able to cope adequately with these ideas. According to Shayer and Adey (1981), only some of fourteen-year-old pupils have reached this level, yet they need to be able to understand the concepts of mitosis and meiosis in order to comprehend topics such as Mendelism of genetics. Therefore, one can assume that students' difficulties in dealing with scientific ideas may originate in the abstract level of the concepts as well as the pupils' cognitive developmental stages (see Chapter four).

In genetics, many researchers have shown that students have serious misunderstandings, even after instruction, concerning the basic scientific content related to biological inheritance. For instance, research has shown that students do not fully understand chromosomes, genes, or alleles (Collins and Stewart, 1989; Albaladejo and Lucas, 1988); they cannot adequately interpret some concepts such as homozygous or heterozygous (Slack and Stewart, 1990); they have alternative views of some processes such as mitosis and meiosis (Kindfield, 1994; Brown, 1990; Stewart *et al.*, 1990); and they do not understand the meanings of probability in relation to genotype and phenotype frequencies in offspring (Browning and Lehman, 1988; Cho *et al.*, 1985). As a consequence, when they are not able fully to understand these matters, students depend on rote learning to pass examinations.

A thorough analysis of the results showed that the traditional teaching strategies have effect on students' meaningful understanding of genetics (Pashley, 1994a; Stewart, 1982a). In the light of Johnstone and Mahmoud's (1981) work, considerable changes were made in the Scottish syllabuses which had also resulted in the difficult topic becoming accessible to students. Moreover, it is believed that teaching which takes students' existing ideas into account will be more effective than teaching which ignores them. Starting from their own common sense ideas, learners become aware of and reason about conceptual relations, or as a process of conceptual refinement, and then replace existing conceptual relations (Cem *et al*., 2003).

3.5 Complexity of genetics: a macro-micro problem

The complex nature of genetics is another reason why genetics is difficult to learn and teach (Bahar *et al*., 1999a). The structure of the knowledge of genetics is complex and students have to use this complex knowledge in solving complex genetics tasks (Collins and Stewart, 1989).

In science education studies, many researchers have noted that, when concepts and processes in a subject belong simultaneously to several levels of organisation, considerable difficulty is encountered when learning the subject (Bronsan, 1990; Lijnse, 1990; Pritchard, 1990; Sequeira and Leite, 1990). Genetics concepts refer to different levels of biological organisation and students have difficulties with linking these different genetics concepts and processes with these different levels.

However, the levels of organization are mentioned differently by researchers in the different science disciplines (Marbach-Ad and Stavy, 2000; Johnstone, 1991; Kapteijn, 1990). Analysis of the nature of genetics leads to a realization that the complexity lies in the fact that the ideas and concepts inherent in them exist on four levels (Figure 3-1):

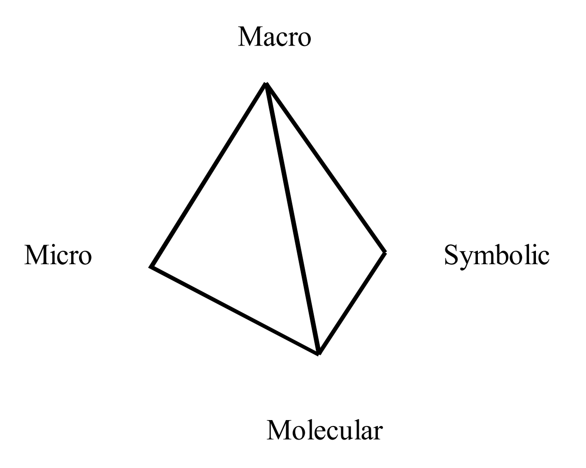


Figure 3-1: The pyramid of genetics concepts.

1. *The macroscopic (organismal) level*: This is the first level at which students can see, touch, smell and describe their properties. In other words, it is a tangible and visible level (Johnstone, 1991). Students can obtain a useful and long lasting learning experience when they deal with macroscopic phenomena at the organismal level. By manipulating an entire plant or animal, all their senses can be used in observation (Kapteijn, 1990).

2. *The microscopic (cellular) level*: This is the second level at which no direct experience is possible through touching objects and an attempt is made to give mental pictures explaining or describing what are observed or mentioned at the macroscopic level. The microscope is positioned between the object and the observer which make even visual observation considerably restricted (Marbach-Ad and Stavy, 2000).

3. *The molecular (biochemical) level*: This is the third level. Biochemical structures are not directly visible at all in living organisms. *In biology, pupils get a glimpse of organic molecules only by using indicators. If a substance is present, it will show itself through a colour, nothing more* (Kapteijn, 1990). In fact, most molecular objects cannot be observed even indirectly, and must be imagined by students (Marbach-Ad and Stavy, 2000).

4. *Symbolic (representational) level*: This is the fourth level of thought in which the students tries to represent observations by symbols, formulae, mathematical manipulations and drawing graphs (Johnstone, 1991).

Kapteijn (1990) expressed the opinion that the macro/micro perspective can be useful in biology education and that concept formation at the cellular and biochemical level is important if we want pupils to learn and understand macroscopic phenomena. However, researchers who deal with the perception of concepts relating to different of organisation generally note that the micro- levels (cellular and molecular) are more difficult to understand than the macroscopic level. It is reasonable to assume that the reason for this is, at least in part, that the micro- levels are generally taught in a theoretical manner. The processes and objects at these levels cannot be touched or directly observed and, in many cases, they cannot be easily extrapolated from observations at the macroscopic level. Nonetheless, students attempt to make such erroneous extrapolations and they make errors as a result.

Genetics is connected with the occurrence of ideas and concepts on these different levels of thought. Observations of morphological characteristics of living things, such as colours of flowers or the height of humans takes place at the macroscopic level and are accessible to the senses. The appeal to cells, gametes, and nucleus, and chromosomes, DNA, genes and alleles to explain the macroscopic level takes students into the microscopic and molecular level, which is not directly accessible to the senses. These are then represented and manipulated by mathematics (ratios and probabilities) which are symbolic (e.g. Aa represents an allele; a pair of gene) of what is happening at the microscopic and molecular level, and giving rise to the macroscopic level (Bahar *et al*., 1999a).

Some researchers think one of the causes that genetics is so difficult is because several levels of organisation must be integrated in order to understand the processes underlying genetic phenomena and to grasp the overall picture of inheritance and genetics. It means that to understand genetics fully, it is necessary to experience all the above four levels. Thus, according to the information processing model, this may pose problems because the working memory has a limited capacity. Using several levels simultaneously is likely to bring about an information overload (see Chapter four).

Bahar *et al*. (1999a) suggested that, in teaching practice, teachers should confine themselves to one level at a time. Students have to develop this thinking on the different levels of thought gradually. Marbach-Ad and Stavy (2000) suggested starting on the macroscopic level and then microscopic level, molecular level and symbolic level, step by step. When dealing with the micro- levels and trying to link the macroscopic with the micro- levels, micro- levels with symbolic level, and even symbolic level with macroscopic level, it would help students for learning genetics/biology.

Another reason for the difficulties encountered, both in understanding the micro- and symbolic levels and in connecting between levels, is either because sometimes one level (e.g. the macroscopic level) 'belongs' to one discipline (e.g. biology), and the other level (e.g. the molecular level) 'belongs' to a different discipline (e.g. chemistry) or concepts from these different levels of biology are dealt with in different chapters of textbooks. Kapteijn (1990) had suggested that more attention needs to be paid to learning activities that aim at integration and not separation of the different levels. However, this assumes that the learners are cognitively capable of such an approach.

Hallden (1988) pointed out that teachers must realise genetics is a complex subject with many inter-related concepts. When genetics is taught at the macroscopic level, students are able to understand what they have been taught. However, when they move to the molecular level, they often fail to grasp the connection between 'genetic materials' and 'genetic traits', and new concepts (at the micro- levels) appear to be meaningless words.

Stewart (1983; 1982a; b) provides another example of the same confusion, noting that it is difficult for students to grasp the connection between meiosis (micro- levels) and Mendelian genetics (macroscopic level).

Boersma (1999) introduced the 'level-matrix', which consists of levels of biological organisation (vertically) and knowledge levels (horizontally) and is designed to develop subject matter sequences. A sequence starts in the cell of the matrix that is defined by the organisational level and the first knowledge level. From there on, it is prescribed to move horizontally (ascending or descending to a next level of biological organisation), or vertically (to a next knowledge level) to an adjacent cell. This procedure can be repeated as long as necessary. However, this was not easy to achieve, mainly because of inadequate time allowance in school.

3.6 The language and terminology

At one level, the importance of language in science education has always been recognised: in order to understand science topics especially in biology, in which Latin and Greek words are heavily used, pupils need to become familiar with a wide range of specialist vocabulary (Bahar, 1996; Selepeng, 1995). As Vygotsky (1962) pointed out, when a child uses words he/she is helped to develop concepts. Language development and conceptual development are inextricably linked. Thought requires language, language requires thought. Viewed from a negative angle, difficulty with language causes difficulty with reasoning (Byrne *et al.*, 1994).

However, though obviously important, this aspect of language is only part of the story. Understanding science is more than just 'knowing the meaning' of particular words and terms, it is about 'making meaning' through exploring how these words and terms relate to each other (Sutton, 1996).

One of the biggest problems of language in science is the vast technical vocabulary with which pupils need to become familiar in order to be able to make sense of what they hear, read and have to use when writing in their lessons. Willington (1983) proposed a four-level taxonomy of words in science. Through doing this, science teachers can become more aware of the language they use in the classrooms.

- The first category is called *naming words*, which denote identifiable, observable, real objects or entities, such as eyes and flowers. Many of these are simply synonyms for everyday words already familiar to pupils.

- The second is *process words* that denote processes that happen in science, e.g. photosynthesis and mitosis.

- The third is *concept words*, e.g. heredity and evolution. This area of learning in science is the one where most learning difficulties are encountered because these are abstract, also these are part of a network of other words. The understanding of one word depends on prior understanding of other words. Moreover, some may have both everyday and scientific meanings, such as consumer and energy.

- Finally, the *language of mathematics*, its words or symbols, is the fourth and highest level of abstraction.

Genetics is an area with a complex and large vocabulary. Bahar *et al*. (1999a) found that students are often not confident about the definitions of the genetics-related words, such as allele, gene and homologous. There is confusion because terms which look and sound very similar, e.g. homologous and homozygous, mitosis and meiosis, and chromosome and chromatid (Cassels and Johnstone, 1978). Moreover, students have the problem of learning the new and abstract words, and at the same time learning new concepts in that vocabulary (Ramorogo and Wood-Robinson, 1995).

According to Johnstone (1991), an unfamiliar word or known word in an unfamiliar context takes up valuable working memory space. Therefore, students cannot process or store the new information and then tend to learn by rote rather than meaningfully (these will be discussed in Chapter four).

In school practice, the genetic vocabulary is introduced to students by three sources: the teachers, the textbook, and requirements of examinations (Pearson and Hughes, 1988a; b). Unfortunately, the vocabulary of genetics is not always used consistently by these three different sources, and, therefore, a source itself can induce confusion and error. Some situations are worse. Genetics' basic concepts are used incorrectly in the textbook and in the classroom (Cho *et al*., 1985), they are used with a different meaning in colloquial language (Albadalejo and Lucas, 1988), or inappropriate metaphors are used (Martins and Ogborn, 1997). Moreover, the genetics terminology is extensive, so textbooks and teachers need to be selective and specific in their use of genetics terms, and avoid using too many synonyms. Students can be easily overwhelmed by the number of new genetics terms.

The discussion among authors on the genetics terminology have showed that using the genetics terminology appropriately is not easy, not even for genetics education researchers (Browning and Lehman, 1991; Smith, 1991). Pearson and Hughes (1988a; b) suggested that an adequate selection in the use of genetic terms in education should be made to prevent extensive terminology and avoid confusion. On the other hand, teachers could encourage pupils to explain their own words, in order to avoid the mere 'parroting' of rote-memorised teachers' language. Through this, pupils and teachers can arrive at shared meaning (Johnstone and Selepeng, 2001).

3.7 The mathematical content of Mendelian genetics tasks

Genetics is almost unique among the sciences, in that its fundamental law, Mendelism, has been built through many experimental processes and were stated as probability laws.

Most students, whether non-science majors or life-sciences majors, have difficulty in using what they learn of basic Mendelian genetics to deduce the underlying genetic rules from the results of crosses (Charlotte, 1998). Although students often understand the probabilistic nature of real-life problems and have no difficulties in determining the chances, they fail when they have to apply the same chance events in the context of genetics (Kinnear, 1983). It seems that students have difficulties in transferring the mathematical knowledge and insights from one context to another.

Bahar *et al*. (1999a) noted that mathematical expressions, which are symbolic, cause problems that learners face. In addition, the symbols were not used consistently by teachers or textbook writers, and the notation in mathematical genetics is a cause of confusion in the mind of many learners.

Moreover, some research found that students are able to answer the genetic probability questions using algorithms and Punnett square, even though when they do not really understand (Kindfield, 1991; Moll and Allen, 1987). Students often manipulate symbols and adjust algorithms without correct insight into the underlying genetics laws (Thomson and Stewart, 1985). Punnett square is also often used routinely by students in solving a genetic problem without considering the probabilistic nature of meiosis and genetics (Kinnear, 1983; Longden, 1982).

3.8 Conclusions

Almost 100 years after the coining of the terms ‘genetics’ (William Bateson in 1906) and ‘gene’ (Wilhelm Johansen in 1909), the field of genetics has much expanded to cover many areas beyond merely the study of inheritance (Chattopadhyay, 2005).

Many science education researchers advocate that genetics instruction raises important political, economic, ethical, and educational questions. Members of society must receive an effective education and develop an adequate understanding of the concepts and processes involved in genetics in order to appreciate these questions and their answers (Sadler *et al.*, 2006; Brock, 1996). Also, they will be better able to understand subjects discussed in the media and be better prepared to participate in major decisions.

In this chapter, the reviewed literature on science education has indicated several major reasons as being problematic when learning genetics. It has been noticed that these different problems are not isolated, but are in a way all related to one another and can reinforce the difficulties students experience (Knippels *et al.*, 2005). Students face problems in the abstract and complex nature of science knowledge, their own ingrained misconceptions, and the large amount of content. Knowledge of the extensive genetic terminology is required for understanding a classic genetic problem. Moreover, they have to do mathematical calculations with those symbols in solving the problem, and to connect these probabilities with biological phenomena (Knippels *et al.*, 2005).

However, students’ ability to deal with formal concepts in a meaningful manner is connected with their level of intellectual and cognitive development. The next chapter will review some of the learning theories and models, with a more detailed discussion of some aspects the psychology of learning. These models led eventually to the powerful predictive models based on information procession.

Chapter Four

Learning Models

4.1 Introduction

The development of a human being from a dependent and relatively non-capable infant into an adaptable and competent adult within a complex society is one of the profoundest things to deliberate. One part of the explanation lies in an understanding of the processes of growth and development, characteristic properties shared by all living things, and the other part lies in learning (Danili, 2001).

Learning is a process by which relatively permanent changes occur in a person's behaviour caused by information and experience (Atkinson *et al.*, 1993). It is not just the acquisition of content imitatingly or the transferring of knowledge from the teacher to the learner. Hamachek (1995) had noted that these changes in a person's behaviour do not solely refer to outcomes that are manifestly observable, but also to attitudes, feelings and intellectual processes that may not be so obvious.

There have been many attempts to describe the human learning process. These models which describe how students learn or think serve as a basis for models of instruction that draw conclusions about how teaching should be carried out (Romberg and Carpenter, 1986) and also provide a useful framework for research in education.

This chapter will look in particular at those models which relate to observations on learning processes in the face of difficulties in the field of science education/genetics education: Piaget's cognitive development theory, Ausubel's meaningful learning model, and the information processing model. The information processing model will be the main theoretical basis for this project.

4.2 Piaget's cognitive development theory

Swiss biologist and psychologist Jean Piaget (1896-1980) is renowned for constructing a highly influential model of child development and learning. His theory is based on the idea that the developing child builds his own cognitive structures. Piaget believed that learning is a physical, biological function of dealing successfully with the environment which is based on two biological tendencies: organization and adaptation (Phillips, 1998).

Organization is important in that a human is designed to organize his/her observation and experience into a coherent set of meanings (Eggen, 1999). It makes the thinking process more efficient. Adaptation is the tendency to adjust to the environment and a process by which the person creates matches between his/her original observation and new one that might not exactly fit together.

These original observations, conceptions or skills are called *schemas* (Piaget, 1962), which direct the way in which the child explores his/her environment. In this way, the child can interact with the world and construct his/her exploratory skills. In this way, the child gains more knowledge of the world and more sophisticated exploratory skills (Atkinson *et al.*, 1993).

In order to adapt to new observation and experience into schemas, *assimilation* or *accommodation* can be used (Pulaski, 1980). The child assimilates that new information by putting it together with internal schemas. If the observation does not fit perfectly into his/her existing schemas, the child may accommodate or modify the old schema to fit the reality (Beard, 1969; Piaget and Inhelder, 1969). All schemas are established on the learner's own observations and experiences (Eggen, 1999). Assimilation and accommodation are the two sides of adaptation. Assimilation refers to the absorbing new knowledge in such a way that it makes sense within existing cognitive structure. It means the child attempts to understand new knowledge founded upon his existing knowledge. Accommodation happens when a child tries to change his/her internal structure to understand a new situation. This is when the child learns to treat the subject differently, so he/she has to adapt his/her way of thinking to this situation.

Assimilation and accommodation work like pendulum swings at advancing our understanding of the world and our competence in it. Both processes are used simultaneously and alternately throughout life. According to Piaget (1962), for a healthy development of a cognitive structure that eventually enables the individual to detect differences and similarities in things, there should be a balance between assimilation and accommodation. This balance which Piaget referred to as *equilibration* is necessary to ensure that the individual develops adequate schema consistent with existing schemas. It is an array of things that the one encounters or experiences. Moreover, this constant adjustment of the balance between assimilation and accommodation is said to start from birth through to adulthood, also it is responsible for the construction of knowledge by the individual (Flavell, 1963).

As Piaget continued his investigation of children's development and learning, he considered that mental development organises these schemas into more complex and integrated ways to produce the adult mind. Piaget also observed that the child's structure develops and grows up through a series of distinct stages, so he developed the idea of stages of cognitive development (Piaget, 1961). Atkinson *et al*. (1993) summarized and listed these four stages, as shown in Table 4-1.

Table 4-1: Piaget's cognitive stages.

Stages of development	Descriptions
Sensorimotor (birth to 2 years old)	• Differentiates self from objects. • Recognises self as agent of action and begins to act intentionally. • Achieves object performance, realising that things exist even when no longer present to the senses.
Pre-operational (2-7 years old)	• Learns to use language and to represent objects by images and words. • Thinking is still egocentric with difficulty in seeing the viewpoint of others. • Classifies objects by a single feature e.g. colour.
Concrete operational (7-11 years old)	• Can think logically about objects and events. • Achieves conservation of number (age 6), mass (age 7) and weight (age 9). • Can classify objects according to several features and can order them in series along a single dimension.
Formal operational (11 years old on)	• Can think logically about abstract proportions. • Can test hypothesis systematically. • Becomes concerned with the hypothetical, the future, and ideological problems.

From Atkinson *et al.*, 1993

Each structural change incorporates and improves upon previous structures. All children develop their own cognitive structure through these four stages in the same order but not at the same rate. The development of schemas begins at birth and culminates in adolescence or later depending on the individual.

Among these stages of cognitive development, only the last two stages are significant in the context of science in secondary education. Johnstone (1987) described them:

> *The concrete operational is characterised by thinking about or doing things with physical objects; ordering, classifying and arranging; manipulating things in the mind; and limited exploration of possibilities. At this stage, the learner is able to solve problems but his solutions are characteristically in terms of direct experiences.*
>
> *By contrast, the formal operational stage is characterised by logical reasoning, drawing conclusions from premises; testing hypotheses; planning experiments; formulating general rules; manipulating propositions in the mind; exploring many possibilities. These characteristic are important in a scientist and teachers would hope to find these in their students when progressing from secondary to higher education.*

Although Piaget's theory of cognitive development has greatly influenced teaching and learning in schools and has had a profound impacted on educational thought and research, there are still some criticisms on his work, which are outlined:

- Piaget did not use sufficiently large samples and standard statistical analysis, so he was accused of not considering the significance and reliability of the data on the validity of his conclusion (Flavell, 1963).
- The boundaries that Piaget used to define the development stages of knowledge construction are too rigid (Ausubel *et al*., 1978). Later work has shown that people do not jump from stage to stage in neat ways. Indeed, each child will go through each stage in their own time, so at a given age not all children are at the same cognitive stage (Eggen, 1999).

- The significance of social interaction and language in children development are underestimated (Bliss, 1995). Piaget thought that the developmental changes in the cognitive structure of the child produce the language development. In contrast, Vygotsky (1986) emphasised the importance of the socio-cultural context of learning and, as Bruner (1996) said, the child's experiences and his/her environment are far more powerful influence on his/her cognitive development than Piaget allowed.

- It has been criticised for over-generalisation on the concept of knowledge development. The universal statements about individuals are not always sufficient to explain individuals' cognitive and affective positions. In fact, the individual differences in personality, gender, intelligence and other factors also affect the ability to progress cognitively (Sutherland, 1992).

Despite these criticises, psychologists still regard Piaget's view as fundamental for modern educational thought and practical teaching and learning (Miller, 1993). It has led not only to the amount of critical research of his original theory but also to a greater understanding of the processes of human cognitive development (Bentham, 2002).

To apply Piaget's theory in the secondary school, educators should know what the students' developmental level is and gear the teaching toward that. When beginning a new topic especially in science/biology, learning should be based on concrete concepts or on the learners' own experiences (Beard, 1969). To understand completely the abstract knowledge directly is impossibility, if pupils are not ready developmentally.

4.3 Ausubel's meaningful learning model

David Ausubel (1918-) is a psychologist who was a follower of Jean Piaget. One of his biggest contributions to the field of psychology and learning is his explanations of meaningful learning. In his view, to learn meaningfully, students must relate new knowledge to what they already know. Ausubel's (1968) famous claim is:

If I had to reduce all of educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.

Previous knowledge of the learner is the key factor of learning in Ausubel's meaningful learning model. The aspect of previous knowledge is perceived as a bank of frameworks in the learner's cognitive structure which can provide association or anchorage for various components of the new knowledge and then grows and develops with time towards formal reasoning (Ausubel, 1978). The nature of the individual's existing knowledge and how it interacts with the new knowledge have determined the varying degrees of meaningful learning.

4.3.1 Meaningful learning and rote learning

In an attempt to acquire meaningful knowledge, the learner can approach the task in two different ways: meaningful learning and rote learning (Hassard, 2000; Good and Brophy, 1990) (Table 4-2).

Table 4-2: Characteristics of meaningful learning and rote learning.

Meaningful learning	Rote learning
• Non-arbitrary, non-verbatim, substantive incorporation of new knowledge into cognitive structure.	• Arbitrary, verbatim, non-substantive incorporation of new knowledge into cognitive structure.
• Deliberate effort to link new knowledge with high order concepts in cognitive structure.	• No effort to integrate new knowledge with existing concepts in cognitive structure.
• Learning related to experiences with events or objects.	• Learning not related to experience with events or objects.
• Affective commitment to relate new knowledge to prior learning.	• No affective commitment to relate new knowledge to prior learning.

From Hassard, 2000

Ausubel and Robinson (1969) believed that the meaningful learning happens when learners possess three requirements:

1. *Relevant to prior knowledge: the material to be learned must be related to some hypothetical cognitive structure consistently and substantively.*
2. *The meaningful material: the learner must possess the relevant cognitive structures to which to relate the material.*
3. *The learner must choose to learn meaningfully: the learner must possess the intent to relate the relevant ideas to the new material non-arbitrarily and substantively.*

The meaningful learning results when the learner consciously and explicitly ties new knowledge to relevant concepts within his/her schemas. When this occurs it produces a series of changes within his/her entire cognitive structure. Existing concepts are modified and new linkages between concepts are formed.

If the learner memorises the new knowledge and adds it to his cognitive structure, without interacting with what already exists, the learning is rote. Rote learning happened when learning is verbatim, sequential and generally not related to the learner's prior knowledge (Table 4-2). According to Ausubel and Robinson (1969), some situations tend to encourage rote learning:

1. *The material to be learned lacks logical meaningfulness.*
2. *The learner lacks the relevant ideas in his own cognitive structure.*
3. *The learner lacks the skills to enable him to learn meaningfully.*

However, it must be pointed out that not all rote learning is useless or that everything can be learned meaningfully. For example, learning the alphabet, a foreign language or in the case of school science, technical terms or formulas by rote may be a valuable tool in bringing ideas together as well as gaining correct answers.

Materials learned that have relation to experiences or memories that are firm in the person's memory are more likely to be retained while rotely learned materials are discrete and isolated entities which have not been related to established concepts and may soon be forgotten (Ausubel, 1962). Johnstone (1997) also described:

> *Meaningful learning is good, well-integrated, branched, retrievable, and usable learning while rote learning is at best, isolated, and boxed learning that relates to nothing else in the mind of the learner.*

Meaningful learning is connected to the process of knowledge retention within cognitive structure. Rote memory works at times for short-term memory as we know from casual meetings with new people and exposure to a new joke. It means rote learning is closely associated with the surface learning approach while meaningful learning tends to correlate with the deep approach towards learning. Therefore, the knowledge can only be effectively retained if it is meaningful, and thus must be processed in a way that it can be subsumed and anchored in the mind.

Using Ausubel's (1968) perspectives, meaningful learning is also called *subsumption* which is the process where new knowledge enters the consciousness and is directed or organized to fit within an already existing larger (more broad or more general) category. He emphasised that new knowledge is not added to existing relevant concepts. Instead, it interacts with these and assimilates into an altered *anchoring concept* (Ausubel *et al.* 1978). Therefore, the new concepts are subsumed into the larger context, subordinate concept (Good and Brophy, 1990). Moreover, Ausubel (1968) thought that the process of subsumption is continuous and its effectiveness depends on how well the subsuming concepts are organized, and the degree of anchorage determines how well the knowledge is retained in the long-term memory.

4.3.2 Reception learning and discovery learning

Ausubel's meaningful learning model concerns both the presentational methods of teaching and the acquisition of knowledge (Ausubel, 1968), which can be represented as the dimensions of reception-discovery learning and meaningful-rote learning respectively.

Ausubel and Robinson (1969) described reception learning and discovery learning as the different ways of presenting knowledge to the learners. According to Larochelle *et al.*

(1998), reception learning is highly teacher-centred in that it views the teacher as the primary source of information and knowledge. The teacher organises the learning materials and presents them to the students in relatively understandable forms. The teacher arranges the conditions under which learning occurs. Under the conditions, all the students need to understand about the learning materials given to them and to internalise or incorporate the contents into their cognitive structure. Thus, reception learning in schools is usually associated with didactic forms of teaching (Ausubel and Robinson, 1969). According to Ausubel *et al*. (1978), concepts, principles and ideas are presented and understood, not discovered.

In contrast with reception learning, discovery learning is based on the learners who make themselves discoveries of new knowledge to be learned through setting them into situations. Learners organise and construct the new information and assimilate and/or accommodate to their existing knowledge. According to Ausubel *et al*. (1978):

> *The learner must rearrange information, integrate it with existing cognitive structure, and reorganise or transform the integrated combination in such a way as to generate a desired end-product or discover a missing means and relationships.*

Bruner, a leading advocate of discovery learning, argued that, when students are motivated by their own curiosity to explore new things, the most meaningful learning can occur (Good and Brophy, 1990). It is important to provide some forms of guidance in a situation that the learning outcomes of discovery learning (Ausubel *et al*., 1978). In discovery learning, the aim is for learners to infer the key concepts and construct significant propositions independently, whereas, in reception learning, concepts and propositions are presented to the pupils by the independent agents (teachers, books, or media). It is believed that discovery learning leads to real knowledge and that the knowledge can be retained better in the long-term memory (Langford, 1989).

However, discovery approach does not guarantee meaningful learning and reception learning can be made meaningful if the material is presented right (Ausubel, 1968). Ausubel also noted that most people learn primarily through reception learning rather than discovery learning. Moreover, discovery learning is cumbersome and largely a waste of time although it is effective in certain situations (Langford, 1989). In the majority of schools, reception instruction has prevailed until nowadays because the teachers have a greater opportunity to check effectiveness in developing conceptual frameworks in the learners' mind within limited time. In fact, the most important element of learning is not so much how information (reception-discovery) is presented but how new information is integrated into an existing knowledge base.

Ausubel *et al*. (1978) stated that both discovery and reception learning can be categorised either as meaningful or rote learning depending on what happens after the material to be learned is presented to the learners (Figure 4-1). The diagram shows the two continuum dimensions of learning types: meaningful-rote versus reception-discovery and the patterns that Ausubel generated to describe these teaching and learning circumstances in relation to the types of learning.

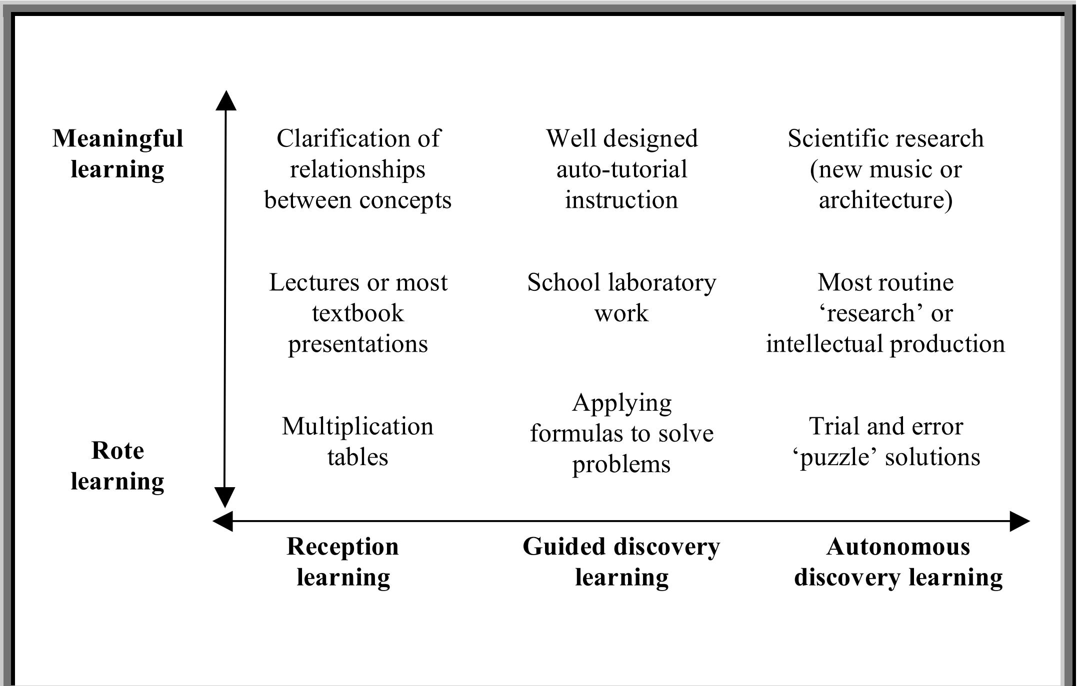


Figure 4-1: Reception learning and discovery learning.

From Ausubel *et al.*, 1978

Within a learning situation, meaningful learning and rote learning are not necessarily considered true divisions of the whole process of knowledge acquisition (Ausubel and Robinson, 1969). In fact, they can happen simultaneously during a lesson. On the other hand, by applying a variety of teaching methods and using different teaching materials, a combination of reception and discovery learning can arise out of that lesson. The difficult task faced by teachers in schools is to determine when and where during an instruction to use each category.

As Johnstone (1987) noted, teaching students' knowledge is not the same as filling empty pots. The information is not just transmitted but constructed and related to meaning in the mind by the learners. Ausubel (1963) suggested that the teacher must progress slowly and methodically with the students at any age level. The most important information must be presented first and everyone in the class must have a great understanding of the information before progressing. Then, by gradually building on what was already learned, the new information is much easier to grasp and appreciate. Moreover, he is adamant that no single method of teaching can effectively enhance meaningful learning or improve the child's level of thinking. Teachers have to plan lessons to include a variety of activities which introduces learners to different ways of presenting information for the learners to comprehend more easily.

Ausubel has significantly contributed to the understanding of learning and his meaningful learning model has been considered by educators to be sensible and consistent with what is going on in current educational practice. When something is meaningfully understood by establishing relationships with previous knowledge, it is retained much longer, can be built upon to acquire further understanding, is usually very versatile in the situations and ways it can be used, and facilitates creativity.

4.4 Information processing model

Information processing is a perspective in the study of cognition and cognitive development in which the human mind is likened to a computer. The basic information processing model is concerned with fundamental mental operations: mainly how information is received, processed, stored and retrieved in the individual's mind. Like the behaviourists, the information processing model is concerned about observable behaviours which respond from stimuli (Barber, 1988); but, unlike behaviourists, it uses those behaviours to make inferences about underlying mental processes that cannot be directly observed (Halliday and Hitch, 1988).

The approach to learning with this model is primarily through the study of memory. It uses a metaphor borrowed from the basic idea of computer science. The similarities between input and output devices and the human sensory-motor systems, between storage and memory, and between programming and learning provided educational psychologists and educators with a useful framework to understand the problems associated with human learning.

Indeed, it is not associated with the work of a single theorist; rather, it builds on the work of a number of researchers. A variety of information processing models have been developed with slight variations on the functions and the relationships between the different components of the human memory system, generally, they share a common paradigm (e.g. Brunning *et al*., 1995; Ashcraft, 1994; Child, 1993; Johnstone, 1993; Sanford, 1985; Atkinson and Shiffrin, 1971).

Among them, the model introduced by Johnstone (1993) will be used in this study, which focuses on learning in the sciences and offers insights and predictions into all aspects of learning. The model is based on ideas from other learning models including Piaget's stages theory, Ausubel's importance of prior knowledge in the meaningful learning, Gagne's learning hierarchy and Pascual-Leone's neo-piagetian model of limited space related to age (Bahar, 1999). It suggests a simplified mechanism of the learning process based on a vast accumulation of experimental evidence and it also explains learning limitations being followed by learning difficulties.

4.4.1 Hypothesis of human memory

From the information processing perspective, a human memory consists of three major components (Brunning *et al*., 1995; Ashcraft, 1994; Barber, 1988; Atkinson and Shiffrin, 1968):

1. *The sensory memory (perception filter or sensory register).*
2. *The short-term memory (working memory).*
3. *The long-term memory.*

During learning, the information is processed through these three modes of memory. The information from external environment is first perceived by the sensory memory, processed in the short-term memory, and then assimilated and accommodated into the long-term memory and stored as cognitive structures or schemas (Figure 4-2).

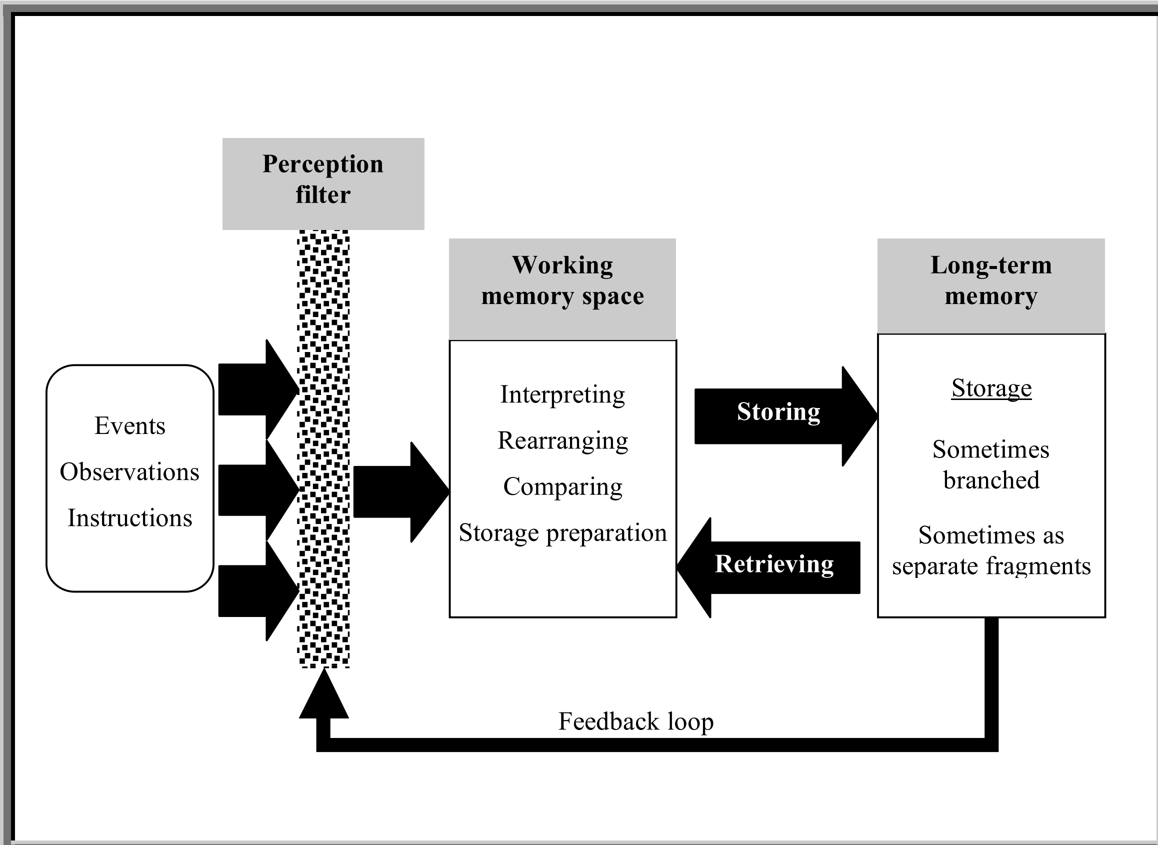


Figure 4-2: The information processing model.

From Johnstone, 1993

Memory is the ability of the brain to select, process, store, retain, and subsequently recall information (Brunning *et al*., 1995). From an information processing perspective, there are three main stages in the formation and retrieval of memory:

- *Encoding* (processing and combining received information).
- *Storage* (creation of a permanent record of the encoded information).
- *Retrieval/Recall* (calling back the stored information in response to some cues for use in some processes or activities).

However, some information is remembered for a period then *forgotten* which may be attributed to a problem with one or some combinations of these stages (Atkinson *et al*., 1993). For the detail of the structure and process of the human memory system in the information processing model will be discussed in turn in the following sections.

4.4.2 Sensory memory (perception filter or sensory register)

Sensory memory, the first integral part of the human memory system that incoming information meets, acts as the buffer for stimuli received through the senses; it holds the information briefly for further processing (Ashcraft, 1998). It is also called the sensory register (Atkinson and Shiffrin, 1968) and perception filter (Johnstone, 1991).

Human sensory memory consists of sensory registers which are linked to five senses: sight, hearing, taste, touch, and smell in order to keep interactions with the external environment (Klatzky, 1975). Educational research naturally has paid more attention to visual sensory memory and auditory sensory memory (Brunning *et al*, 1995; Kellong, 1995; Ashcraft, 1994; Bourne *et al*, 1986).

Sensory memory is affiliated with the transduction of energy (change from one energy form to another). The environment makes available a variety of sources of information (for example, light and sound) and the body has special sensory receptor cells that transduce this external energy to the electrical one which the brain can understand. In the process of transduction, a memory is created. This memory is very short and rapidly lost unless attention is paid to it. The length of time information can be held in the visual registers is less than one second after the stimulus is not longer physically available and about three seconds for hearing (Slavin, 2000; Ashcraft, 1994).

Biggs and Moore (1993) noted that a human’s mind constantly receives a huge amount of information inputs through the five senses, but only a fraction of them can be noticed or handled at any one time and then transferred to the next stage of the memory system. The key point of what information can be noticed depends on whether the person pays attention to it or the information is meaningful for him/her (Johnstone, 1993).

Attention is the active focus on certain stimuli to the exclusion of others. It is involves some sifting or selecting among the various inputs presented to a individual at any instant (Barber, 1988). Attention is severely limited and generally affected by some forces within the learner's external environment and some internal thoughts (Bruning *et al.*, 1995).

The sensory registers function to select or filter what information is perceived important to the learner (Brunning *et al.*, 1995). This selecting process is influenced by many factors which already lie in the long-term memory of the learner, such as personal past experience, existing knowledge (even misconception), attitudes, motivation, and abilities (Slavin, 2000; White, 1988). Johnstone (1997) also commented:

> *The perception filter must be driven by what we already know and understand. Our previous knowledge, biases, prejudices, preferences, likes and dislikes and beliefs must all play a part.*

This is consistent with the work of Ausubel (see section 4.3 in this chapter). Therefore, a variety of factors from the long-term memory provides a mechanism through which the perception filter selects information and assists in the mechanism of encoding filtered information for further processing in the memory system. Finally, the information is passed on to the short-term memory where the subsequence of the processing system takes place.

It is absolutely critical that the learner attends to the information at this initial stage in order to transfer it to the next one (White, 1988). In teaching, educators can follow two basic principles: one is to motivate students' interests by making the teaching material attractive and another is relating new material to what students already known.

4.4.3 Short-term memory (working memory)

Short-term memory, also called working memory, is the part of memory which receives the selected information from perception filter. It temporarily stores and manipulates the information, and then passes on to the long-term memory for storage or discarded (Figure 4-2) (Baddeley, 1986; Atkinson and Siffrin, 1971).

Short-term memory/working memory can be thought as RAM (random-access memory) of computer, which processes the storing information before it is placed into long-term storage on the hard drive. Johnstone (1997) described the working memory's main function:

> *It is the conscious part of the mind that is holding ideas and facts while it thinks about them. It is a shared holding and thinking space where new information coming through the filter consciously interacts with itself and with information drawn from long-term memory store in order to make sense.*

In fact, the information that working memory holds includes recently processed sensory inputs from perception filter, the prior knowledge retrieved from long-term memory for interacting the inputs to make sense, and the results of recent mental processing. It processes these through the operations such as interpreting, rearranging, comparing and storage preparing etc. (so-called working memory).

Many studies in information processing have suggested that working memory is a temporary storage system and of limited capacity (Bruning *et al*., 1995). It is believed that the working memory can only hold information for a few seconds (so-called short-term memory); longer if there is rehearsal (Slavin, 2000). It is also easily disrupted by interference and deterioration with age (Brunning *et al*., 1995).

In addition, Miller (1956) found that the average capacity limit associated with working memory of an adult is approximately 7 (±2) elements, called *chunks*, regardless of whether the elements are digits, letters, words, or other units. This means that an adult can think about around seven separate things simultaneously.

Cowan (2001) proposed that working memory has a capacity of about 4 chunks in adolescents. It is known to grow on average by one unit for each two years until about age 16. The growth of the working memory space also supports the observed Piaget's development stages of cognitive structure (see section 4.2 in this chapter). Moreover, a developed individual cannot expand the maximum number of chunks and effectiveness decreases with ageing (Bourne *et al*., 1986).

Later research revealed that span of the working memory also depends on the category of chunks used and the feature of the chunks. It was found that the working memory span is around seven for digits, around six for letters, and around five for words. Also, the working memory span is lower for long words than for short words. Moreover, memory span for verbal content is strongly affected by the time it takes to speak the content aloud, and on the lexical status of the content (Hulme *et al*., 1995).

Nevertheless, it is possible to reduce the load on the working memory to overcome the limited capacity. In fact, one chunk which is perceived as one unit of information is in the control of the learners. In other words, a chunk can be a single stimulus such as a letter or a number, and it can also be a larger unit such as a word or a phrase. Chunking is the process of grouping information as a unit. By chunking, a learner can hold more information within the limited working memory, so learning becomes easier. For example, H-O-R-S-E occupies five spaces of the working memory for the beginner. After learning, students come to recognize it as one word HORSE using only one space of the working memory (Jung, 2005).

By the process of chunking, the working space capacity can appear to increase, although the capacity is still 7 ± 2. Because the learner can arrange items in groups of data, more space is available in the working memory, so they can hold more information at the same time. Thus, the more information students can make into a recognizable group by means of chunking, the more complicated ideas they are able to handle (Bourne *et al*., 1986). According to Searleman and Hermann (1994), the working memory improves if the pieces of information are familiar, frequent, or logically related to each other. On the other hand, when studying in an unfamiliar area, less information is chunked, and the demands on the working memory increase (Herron, 1996). The idea that learning happens if the information can connect to the existing knowledge coincides with the idea of Ausubel's meaningful learning (see section 4.3 in this chapter).

Based on this principle, learning to chunk information will increase the amount of information units contained in each chunk of a learner's mind, so it will help to improve memory and learning (Bourne *et al*., 1986). However, it is not easy to teach chunking skills within the limited time, because it is controlled by the individual's experiences, previous knowledge and acquired skills (Johnstone and El-Banna, 1986). Due to these realistic reasons, although chunking skills do help reducing the load of information on the working memory, the limited working memory capacity is still a major limiting factor in all learning.

Briefly, working memory is the limited space for holding information temporarily and processing it to make sense, to solve problems, and to make decisions (Brunning *et al*, 1995). After that, the processed material in the working memory is passed into the long-term memory for storing. It can be recalled back to help with the new information processing in working space when needed (Johnstone, 1997).

When the new knowledge is equal to or less than learners' working memory space, learners are able to handle it confidently. On the other hand, if the new knowledge which the teacher teaches at one time or in one class reaches the limits of the working space, an overloading in the working memory may occur (Barber, 1988). Johnstone (1997) indicated that:

> *If there is too much to hold, there is not enough space for processing; if a lot of processing is required, it cannot hold much.*

Working memory can be easily overloaded when the new knowledge is large, irrelevant information, novel, abstract concepts, unfamiliar terms, contexts, or difficult formulas (Cassels and Johnstone, 1982). Unfortunately, the learning sciences often face these situations and they thus cause difficulties. For example, during a laboratory experiment, students have to deal with many tasks at the same time: the knowledge of theories, names of apparatus and materials, operation skills, and new experimental instructions. If the quantity of information being presented to students in the laboratory is beyond their working memory capacity, then they eventually lose concentration and subsequent attainment (Johnstone and Wham, 1982).

Johnstone and Wham (1982) pointed out that the overloading of the working space occurs when the students cannot distinguish the unnecessary information (noise) from the essential information (signal). For instance, during lectures, when all the student's working memory space is devoted to take down notes from the board and/or from the lecturer's spoken words, little space is left for making sense of what they are writing down and understanding them (Johnstone, 1999). Overloading of the working memory can also occur in examinations, especially in a conceptual subject, like Newton's laws of motion and Mendelian genetics. An overloading may make further demands on a student by requiring him/her to break down a question into sub-goals and chunk information and then into usable units for use in the working memory (Johnstone, 1988). Thus, for a student with a limited working memory capacity, the irrelevant information may lead to brief and incomplete answers and worsen his/her performance.

Because the working space has limited capacity and this cannot be changed, learning demand has to be kept below the working memory capacity of the learner and chunking strategies can also be developed in order to help a student to operate beyond his capacity. For reducing the extraneous noise, Case (1974) and Pascual-Leone (1970) suggested that the designing of the effective instruction with a minimum load on the working memory must highlight the information to which the subject must attend and reducing to a bare minimum numbers of items of information that requires the attention of students. Moreover, teachers could give prominence by speeches objectives clearly, organising the teaching materials carefully, and even using learners' language (Johnstone and Wham, 1982).

Bahar (1999) had summarised some principles in order to facilitate teaching and learning processes:

1. *Teachers and textbook writers should keep the content of the information at a minimum and within the capacity of students.*

2. *Irrelevant and unimportant information should be avoided and the information that is fundamental to understand the topic should be made obvious to first time learners.*

3. *The information should be presented to the students in a language which should be easy enough to understand, and also teachers and textbook writers need to be selective in the terminology they use.*

4. *Because chunking certainly reduces memory load, teachers should train students to see things as larger and fewer chunks.*

4.4.4 Long-term memory

After the working memory manipulates the selected information from perception filter, the processed information passes on to the long-term memory (Figure 4-2) (Baddeley, 1986; Atkinson and Siffrin, 1971). Long-term memory is the ultimate destination for the information to store, discard, or somehow store then discard (Ashcraft, 1994). Sensory memory and working memory relate to the information instantly experienced while long-term memory is a permanent repository of information that people accumulate day by day throughout life (Brunning *et al.*, 1995) (Table 4-3). The limits of its capacity are still unknown (Solso, 1998).

Table 4-3: Differences between the three stores of human memory.

Feature	Sensory memory	Short-term memory	Long-term memory
Entry of information	Pre-attentive	Requires attention	Rehearsal
Maintenance of information	Not possible	Continued attention, rehearsal	Repetition organisation
Format of information	Literal copy of input	Phonemic, probably visual, possible semantic	Largely semantic, some auditory
Capacity	Large	Small	No known limit
Information loss	Decay	Displacement, possible loss	Deletion, loss of accessibility or interference
Trace duration	0.25 to 2 seconds	Around 30 seconds	Minutes to years
Retrieval	Readout	Probably automatic, consciousness temporal, phonemic	Retrieval item cues, possible search process

From Craik and Lockhart, 1972

Information is stored in the long-term memory after being attended by the sensory memory and processed by the working memory. To be stored in the long-term memory, information must be semantically encoded and placed into it in an organized manner. Various theories suggest alternate forms of how the long-term memory is organized with the final conclusion, however, much more research remains are still to be done. It is believed that encoding can take many forms, such as propositions (as hierarchical "tree" structures), topically (as in paragraphs), spatially (as in matrices or diagrams), or detailed pictures or images.

It is also believed that when the information is stored in an organized manner, there are many interconnections exist between various pieces of that stored data or schemas (Anderson, 1993). When new information comes into the long-term memory, it activates one schema which also activates ones linked closely in some kinds of ways. This means when the information is presented then relevant knowledge will also be called up (Johnstone, 1997).

According to Johnstone (1997), the important of the long-term memory is storing information for recall. There may at least four ways:

1. *The new knowledge finds a good fit to existing knowledge and is merged to enrich the existing knowledge and understanding (correctly filed).*
   This is what Ausubel called meaningful learning. Based on the constructivist point of view, the knowledge has to be reconstructed into the learner's own ways. This meaningful memorisation is easier to recall and almost never lost.

2. *The new knowledge seems to find a good fit (or at least a reasonable fit) with existing knowledge and is attached and stored, but is, in fact, a misfit (a misfiling).*
   This way of storage leads to misconceptions, which may disturb the selection in later perception and provide wrong ideas for working memory. It is one of the biggest problems in learning and very persistent and very hard to change.

3. *Storage can often have a linear sequence built into it, and that may be the sequence in which things were taught.*
   This is linear memorisation that can be accessed in only one way but it is often slow and needs a lot of effort, such as alphabet and Arabic numerals.

4. *The last type of memorization is that which occurs when the learner can find no connection which to attach the new knowledge.*
   Because it does not fit into any part of the existing knowledge, it can be easily lost, consciously rejected and very difficult to retrieve. Ausubel described this as rote learning.

Therefore, the information which is potentially important, interesting, or useful will be stored in different ways for future recall, whereas the more trivial and unimportant information will tend to be ignored or discarded (Johnstone, 1997). If learning occurred, information is retrievable from the long-term memory. Cues are used to locate and copy match the information from the long-term memory to the working memory for conscious review. This process is very personal (Johnstone, 1997).

In sum, long-term memory helps to activate and control the perception filter. It provides information, cognitive skills and chunking procedures to the working memory. Also, it acts as a reservoir of held knowledge, experiences and beliefs that mark us out as indivdual people and personalities (Johnstone, 1993). On the other hand, what is available in the long-term memory is very crucial for the selecting and processing information which is compatible or not with what is coming in from outside (Driver *et al*, 1985)

4.5 Conclusions

Learning for understanding can be achieved if educators pay more attention to the quality of students learning processes rather then emphasising the transmission of knowledge. This chapter has described some of the learning models which relate to observations on how students learn or think in the face of difficulties in the field of science education that could serve as a basis for models of science instruction.

Firstly, this chapter has reviewed the contributions of Piaget and Ausubel. Piaget, while recognizing the contribution of environment, explored changes in internal cognitive structure. He identified the stages of mental growth and emphasised the developmental nature of learning. He also broke free from the view that children learned like adults and that teaching was not only knowledge transmitted to the learners. Ausubel offered very important clarifications on the learning processes, especially relating to the meaningful learning. He emphasised the importance of existing knowledge in providing the basis for further learning and the need for the learner to be actively involved in the learning process.

Furthermore, the information processing model gives us insight into the cognitive nature of the human thought process. From initial attention, by an individual, to an emitted stimulus through feedback and perceived performance, a thought process goes full cycle. In the information processing model, knowledge is seen as something cohesive and holistic in the long-term memory, which provides scaffolding for later learning (Atkins *et al*., 1992). Johnstone (1993) interpreted the way in which the learner processes information, with the limitations of working memory space being critical from his extensive empirical studies of learning in the sciences. In his model, he brought together the ideas of Piaget and Ausubel as well as offering explanations of why difficulties and how misconceptions occur in learning science.

Hartley (1998) had usefully drawn out some of the key principles of learning associated with cognitive psychology. The principles he identified are:

- *Instruction should be well-organized*: Well-organized materials are easier to learn and to remember.
- *Instruction should be clearly structured*: Subject matters are said to have inherent structures, logical relationships between key ideas and concepts, which link the parts together.
- *The perceptual features of the task are important*: Learners attend selectively to different aspects of the environment. Thus, the way a problem is displayed is important if learners are to understand it.
- *Prior knowledge is important*: Things must fit with what is already known if it is to be learnt.
- *Differences between individuals are important as they will affect learning*: Differences in cognitive styles or methods of approach influence learning.
- *Cognitive feedback gives information to learners about their success or failure concerning the task at hand*: Reinforcement can come through giving information, a ‘knowledge of results', rather than simply a reward.

Knowing what occurs in the various phases of the information processing provides instructional designers an advantage in ensuring that planned instruction facilitates the desired learning outcome. It is imperative to design instruction to facilitate learning. Gagne and Medsker (1996) noted: *training should support the cognitive processes of the brain by activating mental sets that affect attention and selective perception, enhance encoding by providing necessary organization for the new data, and maintain executive control that keeps the instruction going in the right direction*. Establishing and employing an effective learning strategy (i.e., sequence, organization and structure) is the key to the successful encoding of information into long-term memory and to achieve the real understanding and meaningful learning.

Chapter Five

Methodology

5.1 Introduction

In this chapter, the focus will be on the methodology which has been employed in this research study. This includes the measurement of the working memory capacity and the extent of field dependence/field independence, the use of the structural communication grids, word association tests, along with attitude measurement. The techniques are reviewed against the background of the literature, but also the way the methods are used along with their strengths and weaknesses.

5.2 Working memory

As noted in section 4.4.3 of Chapter four, the working memory is (Johnstone, 1984):

> *The part of the brain where we hold information, work upon it, organize it and shape it before storing it in long-term memory for further use.*

However, the working memory can easily be overloaded in learning situations when the amount of information exceeds the upper limit of the working memory space (Barber, 1988; Cassels and Johnstone, 1982). For adolescents, this can happen more easily because of their undeveloped capacity: the working memory capacity grows with age.

When studying genetics, especially for the first time, there seem to be several causes of the leaning difficulties (mentioned in Chapter three), such as the large amount of content, the complex and large technical vocabulary, the need to hold many ideas in mind at the same time, and ingrained misconceptions etc (Knippels *et al*., 2000; Selepeng, 2000; 1995;

MacGuire and Johnstone, 1987; Cassel and Johnstone, 1983). These can take up much working memory space and students cannot process or store new information properly.

Moreover, various researches found that working memory capacity has significant effects on students' problem solving performance (e.g. Chen, 2004; Colom *et al*., 2003; Johnstone *et al*., 1993; Geary and Widaman, 1992; Opdenacker *et al*., 1990; Johnstone and El-Banna, 1986). Thus, the working memory capacity can be considered to be likely to be one of the key factors effecting the learning of genetics in secondary schools.

5.2.1 Working memory and achievement

Many studies have been carried out looking at the relationships between the working memory of students and their performance in examinations and problem solving tasks. Johnstone and El-Banna (1986) investigated the effects of the working memory on students' problem solving performance in chemistry and they demonstrated a very significant correlation between them. They also found that students of a given working memory capacity would successfully answer questions with increasing complexity (number of thought steps) until their working memory capacity was exceeded, at which point their performance declined dramatically (Figure 5-1).

Colom *et al*. (2003) noted that students who perform well in tests tend to have high working memory capacity. It may be because high working memory capacity enables them to perform complex cognitive operations, such as inductive and deductive reasoning as well as abstraction. Many studies have also come to the same conclusion, such as Opdenacker *et al*. (1990) with undergraduate medical students solving chemistry problems, Johnstone *et al*. (1993) and Chen (2004) with students solving physics problems, Geary and Widaman (1992) and Al-Enezi (2004) with secondary students solving mathematics problems, and Bahar (1999) with biology problems. In addition, a very recent study has shown that working memory capacity has a small but significant effect on test performance when recall skills are being employed and that this applies across many subject areas (Hindal, 2007).

On the other hand, Johnstone and El-Banna (1986) also found importantly that a minority of students continue to operate efficiently with problems which exceed their capacity. These results suggested that a student with a small working memory space can still solve problems and is capable of learning. Even though the working memory space has a limited capacity and cannot be changed, a student can employ the strategy of chunking and that enables him/her to use limited working space more efficiently. However, it is difficult for a new learner to develop a strategy of chunking in a new area (Bahar, 1999). However, if the teaching strategy can take into account a student's limited working memory capacity as a limiting factor in order to help a student to operate beyond his/her capacity, a student with a small working memory space still could be able to learn successfully.

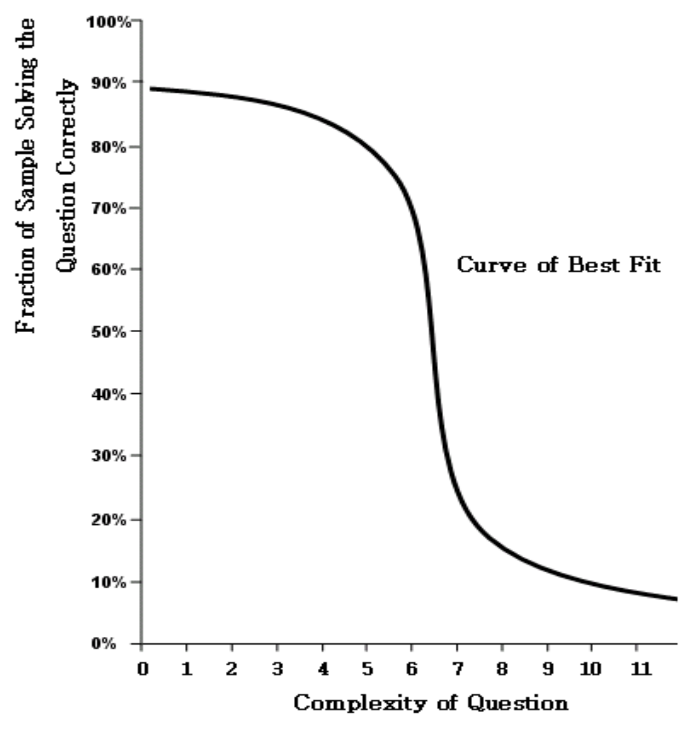


Figure 5-1: Students' performance vs. complexity of questions.
(Students have success with a series of questions of increasing complexity until a certain point, after which most students fail.)

Johnstone and El-Banna, 1986

5.2.2 Measurement of the working memory capacity

There are a number of methods available to measure the capacity of the working memory space of an individual. The traditional span tasks with digits or words and the figural intersection test are used commonly (Oberauer *et al*., 2003; Pascual-Leone, 1974). Although the approaches are slightly different, the results obtained by individuals from the digit span tasks and the figural intersection test are very highly correlated (Su, 1991; Pascal-Leone, 1974).

In the *digit span task*, the subject is read a series of digits (e.g. 2, 0, 7) and they are required to repeat these digits back immediately. They are then given a slightly longer list (e.g. 1, 9, 7, 2) also required to repeat back immediately and so on. When mistakes start to happen, it indicates that working memory space cannot hold the numbers of digits. At the end, the number of digits in the test is equal to the score given if the question is answered correctly and the biggest score is considered to be the size of the participant's working memory. This task draws directly on the use of the working memory as a short-term memory.

Some methods of measuring working memory capacity involve holding and processing information. For example, in the *digit span backwards task*, similar to digit span task, the subject is given a series of digits (e.g. 0, 2, 7) and participants must recall them in reverse order (e.g. 7, 2, 0). After that, the subject is given a slightly longer numeral and so on until mistakes start to happen. The biggest number of digits which participants can answer correctly is considered to be his/her working memory space.

Another method is where the subject is given a date in words, (for example, Twenty-seventh of March) and participants must respond by not only converting the date into digits (e.g. 2, 7, 3), but also arranging them in numerical order from the smallest to largest (e.g. 2, 3, 7). Again, the subject is then given a slightly longer date continuously until mistakes start to happen and the question's numerals indicative of the working memory capacity. However, this is not suitable for the participants whose first language is not English, because participants need to translate into the language they feel comfortable with and which could occupy some space of the working memory. Thus, it may underestimate the real working memory capacity of participants. The importance of language cannot be underestimated and, in one study, it was found that the measured working memory capacity fell by slightly over one unit on average when the subjects were using a second language (Johnstone and Selepeng, 2001).

Other measures involve using visual tasks. In the *figural intersection test* (Pascual-Leone, 1970), the information is given the simple geometric shapes (Figure 5-2). Students are required to shade in a common area from increasing complex patterns of overlapping shapes. This test measures the quantity of information which can be held and processed in participant's working memory at one time, and this also was used in this study.

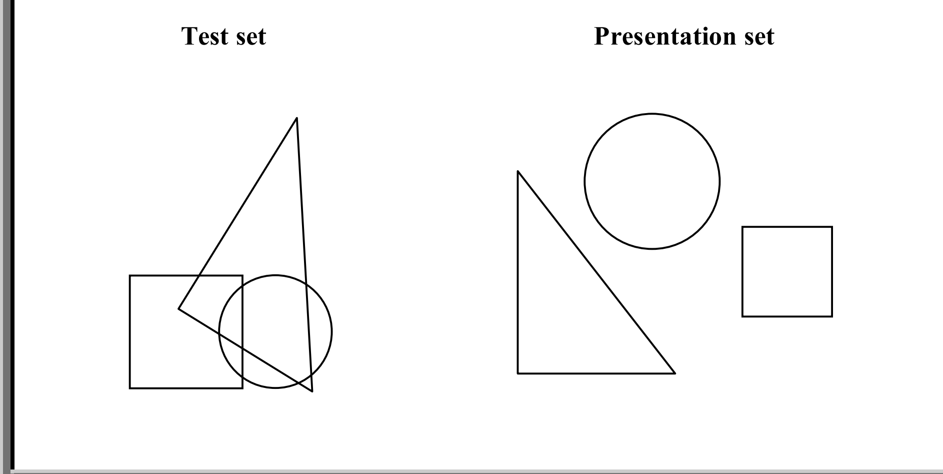


Figure 5-2: One example of the figural intersection test.

Pascual-Leone, 1970

The figural intersection test gives the participant two sets of simple geometric shapes (Figure 5-2). They are the presentation set and the test set. The presentation set is on the right-hand side which consists of a number of simple shapes separated from each other. On the left-hand side, the test set consists of the same shapes but overlapping. Thus, there exists a common area which is inside all of the shapes. Participants are required to look for and shade in a common area from the overlapping shapes in the test set. In some questions, there are some misleading irrelevant shapes in the test set which are not present in the presentation set. This test has 36 questions in total and shown in Appendix A.

The number of shapes in one question varies from two to nine. The number of shapes in the test set is equal to the score given if the question is answered correctly and the final score is considered to be the size of the participant's working memory space. For instance, if a participant identifies the common area correctly up to five overlapping shapes, he/she is considered to have a working memory space equal to five. The test is timed and every question has to be completed in about 25 seconds.

5.3 Field dependence/field independence of cognitive style

The *field dependence/field independence* cognitive style is one of the most widely studied cognitive styles, with the broadest applications to the problems of education (e.g. Tinajero and Paramo, 1998; Green, 1985; Witkin and Goodenough, 1981; Messick, 1976).

5.3.1 Cognitive styles

Individual differences play an important role in the individual learning processes. Every individual has his/her preferred way and habitual pattern for collecting, processing, and organising information into beneficial knowledge (Riding and Rayner, 1999; Cross, 1976). Differences that exist in the individual's cognitive structure enable the individual to have different cognitive styles of learning (Witkin, 1978). Research has showed that individual differences in cognitive styles influence various aspects of learning, such as perception, motivation, creativity, information processing, communicating, problem solving, decision-making, and learning performance (Messick, 1984; Witkin and Goodenough, 1981).

Many definitions of cognitive styles have been offered:

- *The characteristic, self-consistent modes of functioning, which individuals show in their perceptual and intellectual activities* (Witkin, *et al*., 1971).
- *An individual's characteristic and consistent approach to organising and processing information* (Tennant, 1988).

- *Cognitive styles are characteristic modes of perceiving, remembering, thinking, problem solving, and decision making that are reflective of information processing regularities that develop in congenial ways* (Messick, 1993).

- *Cognitive styles identify the ways individuals react to different situations and they include stable attitude, preference, or habitual strategies that distinguish the individual styles of perceiving, remembering, thinking and problem solving* (Saracko, 1997).

In the light of these definitions, we know a cognitive style as the way an individual perceives environmental stimuli, and organises and uses information. A cognitive style influences how the individual looks at his/her environment for information, how the individual organises and interprets this information, and how the individual uses these interpretations for guiding his/her actions (Hayes and Allinson, 1998).

There are three main attributes of cognitive styles: the bipolar dimension, consistency across domains, and stability over time. Firstly, the attribute of bipolarity with regard to level makes the dimensions of cognitive style value neutral. There is no issue of good or bad since each pole has its adaptive value in different contexts (Green, 1985; Witkin and Goodenough, 1981). However, while this view is expressed widely in the literature, it has been found consistently that being field independent and divergent (for example) are always favourable in gaining higher examination and test scores in school and university subjects (Danili, 2004) (these will be discussed in next section).

Secondly, cognitive styles are thought to be relatively stable ways by which an individual approaches a learning task across varying domains (Kahtz and Kling, 1999). Finally, Witkin and Goodenough (1981) and Cross (1976) indicated that cognitive styles are ways of moving towards goals rather than goal attainment and they tend to show a consistent pattern over time. However, they are not totally unchangeable (Leonard and Straus, 1997). Therefore, it can be deduced that any educational implications of cognitive styles may have long-term validity.

On the other hand, different theorists have been working with different concepts over the years and these have led to the development of a large variety of style dimensions (Riding and Cheema, 1991), such as field dependence/field independence (Witkin, 1964), sharpener/leveller (Holzman and Klein, 1954), convergent/divergent (Hudson, 1966), reflection/impulsivity (Kagan, 1965), assimilator/explorer (Kaufmann, 1979), adaptor/innovator (Kirton, 1976), analytic/holistic (Miller, 1987), and left-brain/right-brain (Entwistle, 1981) etc.

Among these variables, the field dependent/field independent dimension has emerged as one of the most widely studied cognitive styles with the broadest application to the problems of education (Tinajero and Paramo, 1997; Rollock, 1992). Also many research studies have found that field dependence/field independence has significantly correlated with the effective use of the working memory and academic achievement in sciences (Tinajero and Paramo, 1997; MacDonald, 1984; Witkin *et al*., 1977; Case and Globerson, 1974; Case, 1974; Pascual-Leone, 1970). Thus, this part of the study will look into the field dependent/field independent construct and review the research studies carried out in this area.

5.3.2 Characteristics of field dependence/field independence

As mentioned before, when learners approach a mass of information, or stimulus complex, they respond in various ways with a view to making sense of it. However, some of the information within the complex matrix of information is not necessary for the task in hand and, indeed, may even be disturbing. The ability to select the most important pieces of information, whether they are the most obvious or noticeable, is related to the learner's field dependence/field independence of cognitive style.

The field dependent/field independent construct originated in Witkin's work (Witkin and Goodenough, 1981; Witkin, 1977; 1974; Witkin *et al*., 1977; 1974; Witkin *et al*., 1962). It has been the most researched of all cognitive styles and had wide applications to the problems of education (Tinajero and Paramo, 1997; Rollock, 1992; Goldstein and Blackman, 1978; Messick, 1976). Witkin and Goodenough (1981) explained the field dependence/field independence as:

- Field independence (FI): Individual who can easily break up an organised field and separate relevant material from its context.

- Field dependence (FD): Individual who has insufficiently separated an item from its context and readily accepts the dominating field or context.

Johnstone and Al-Naeme (1991) described the FD/FI as the ability of the person to discern signal (relevant materials) from noise (the incidental and peripheral materials) in a confusing background. The ability provides a structure for an ambiguous stimulus complex, breaks up an organised field into its basic elements and provides a different organisation to a field than that which is suggested by the inherent structure of the stimulus complex (Riding and Cheema, 1991).

Witkin and Goodenough (1981) also noted that persons who tend to operate on the field independence end of the cognitive style continuum tend to perceive themselves as more segregated from their environments; these persons have a relatively analytical cognitive style in their abilities and interests and they are more likely to analyse a field when the field is organised or to organise a field that lacks it. Also, they are more capable at cognitive restructuring ability than the field dependent individuals. This involves the ability to distinguish the parts of an organised complex field as well as ordering or providing a structure that lacks one, or imposing a different organisation on a field to that which is suggested by its inherent organisation (Riding and Cheema, 1991; Witkin and Goodenough, 1981; Witkin *et al*., 1977).

Persons who tend to operate on the field dependence end of the continuum, on the other hand, tend to be less able either to distinguish among or to reorganise stimuli; the field dependent persons have a relatively global cognitive style and they are more likely to perceive a field as it is without analysing and structuring it. Also, they are easily distracted or accept the dominant message of the field by the visually striking or salient, but irrelevant, information, so that they tend to receive the organisation of the field as given (Witkin and Goodenough, 1981; Witkin *et al*., 1977).

Moreover, more field dependent persons tend to be more social in their abilities and interests. They pay more attention to the significant social aspects of their environment and show less self-segregation from the group or society (Goodenough, 1976; Witkin, 1974). They tend to acquire significant social cues and favour occupations that involve contact with people and that are popular within a group (Witkin *et al.*, 1974; Ruble and Nakamura, 1972).

Garger and Guild (1987) have reviewed the literature and summarised the differences of characteristics of the field dependent and the field independent learners (Table 5-1):

Table 5-1: Characteristics of field dependent/independent learners.

Field Dependence	Field Independence
• Perceives and approaches things globally.	• Perceives and approaches things analytically.
• Experiences in global fashion and adheres to structures as given.	• Experiences in an articulate fashion and imposes structures of restrictions.
• Makes broad general distinctions among concepts and sees relationships.	• Makes specific concept distinctions and little overlap.
• Social orientation. Tend to be influenced by peers.	• Impersonal orientation. Less likely to seek peer input.
• Learns material with social content best.	• Learns social material only if have to.
• Attends best to material relevant to own experience.	• Interested in new concepts for their own sake.
• Requires externally defined goals and reinforcements.	• Has self-defined goals and reinforcements.
• Needs organisation provided.	• Can self-structure situations.
• More affected by criticisms.	• Less affected by criticisms.
• Uses spectator approach for concept attainment. Attend to salient cues first, regardless of relevancy.	• Uses hypothesis-testing approach to attain concepts. Sample more cues, regardless of saliency.
• Extrinsically motivated.	• Intrinsically motivated.

Garger and Guild, 1987

It should be noted that there are some factors that affect the degree to which an individual is either the field dependence or the field independence (Ghani, 2004):

1. *Age*: Children are generally field dependent, but their field independence increases as they become adults. Adults (especially adult learners) are more field independent (Gurley, 1984). After that time, the field independence gradually decreases throughout the remainder of life, with older people tending to be more field dependent than their younger cohorts (Witkin *et al*., 1971).

2. *Gender*: Studies showed that males achieve better scores in the FD/FI tests. However, the effect of sex on the FD/FI is so small that this factor is practically insignificant (Musser, 1998).

3. *Socio-economic status*: Students from lower socio-economic class are found to be more field dependent than students from the higher socio-economic background (Forns-Santacana *et al*., 1993).

4. *Childhood upbringing*: The studies by Witkin showed that when there is strong emphasis on obedience to parental authority and external control of impulses, the child will likely become relatively field dependent. When there is encouragement within the family for the child to develop separate, autonomous functioning, the child will become relatively field independent (Korchin, 1986).

5. *Hemispheric lateralisation*: Research founded that left-handed individuals are more field dependent than right-handed individuals (Pizzamiglio, 1974; Silverman *et al.*, 1966).

5.3.3 Measurement of field dependence/field independence levels

In order to determine an individual's level of the FD/FI, two similar instruments were produced, the *embedded figures test* (EFT) and the *group embedded figures test* (GEFT) (Witkin *et al*., 1971). In both tests, the content field is a distracting or confusing background in order to measure an individual's ability to recognise and identify a simple geometric shape from there. These instruments are designed to distinguish the field independence from the field dependence of cognitive style; a rating which is claimed to be value-neutral.

The EFT is an individually administered test, which is designed to measure disembedding, a restructuring skill. The test is adapted from Gottschaldt's figures by adding colored patterns to increase complexity. Each complex figure includes an embedded simple figure, which the subject is to identify as quickly as possible; there are 24 figures in the EFT. The group version, GEFT, is a paper-and-pencil instrument which requires participants to attempt to recognise the simple shape from a more complex pattern and thus to restructure information as a correlated core skill of the FD/FI (Witkin *et al*., 1977) (Figure 5-3).

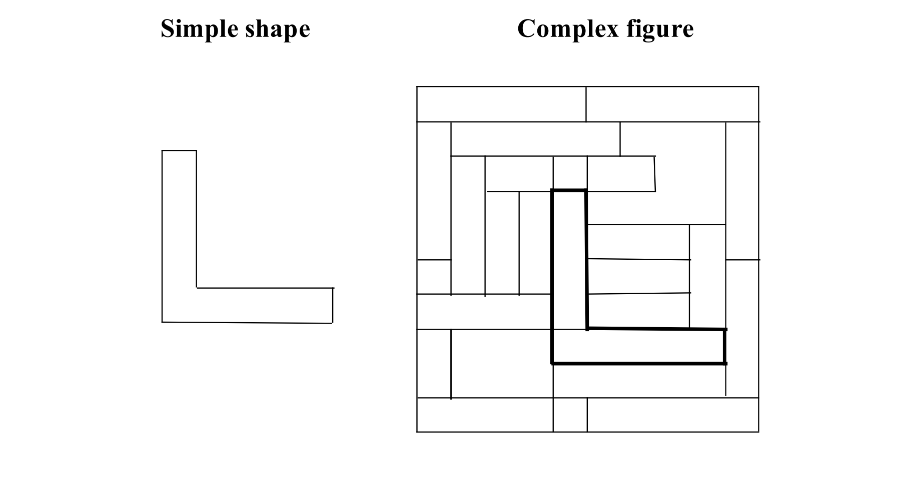


Figure 5-3: One example of the group embedded figures test.

Witkin *et al*., 1977

The more shapes correctly discerned by the participant, the better he/she is at this disembedding process and is therefore said to be field independent, and vice versa for field dependence. According to Witkin *et al.* (1977), the classifications of the field dependence/field independence are not discrete. Rather, they are extremes of a continuum. Those of intermediate ability are classed as the *field mixed* or *field neutral* (Liu and Reed, 1994; Dyer, 1995) or the *field intermediate* (Bahar and Hansell, 2000). Such people do not have a clear orientation. It must be pointed out that being strongly field independent or field dependent is neither good nor bad in itself and that scores on the GEFT form a normal distribution (Witkin *et al.* 1971).

In this research study, a version widely used by many researchers, the GEFT, is used. Many researchers have evaluated the validity and reliability and came out with 'desirable measurement characteristics' as a conclusion (Terrell, 2002; Thompson and Melancon, 1987). The test includes 20 complex figures, with two other figures used as examples. Simple shapes are located after instruction pages of the GEFT booklet as a specimen of the type to be found. Students are required to recognize and identify a hidden simple shape in each of the set of complex figures and trace it in pen or pencil over the lines of the complex figure. It is the same size, in the same proportions, faces in the same direction, and appears only once with the complex figures as when it appeared alone (Figure 5-3). Students are given 15 minutes to complete the test. The entire test as well as the solution is given in Appendix B.

The main scoring scheme is to give one point for finding a correct simple shape embedded in a complex figure. The instrument is scored from 0 to 20 with higher scores indicating a higher degree of the field independence. Different studies have used different cut-off criteria to classify individuals as the field dependence or the field independence. However, to create these categories for this study, a formula derived from the one used by many researchers (e.g. Ghani, 2004; Bahar, 1999; Al-Naeme, 1991) was employed. Participants who scored more than a half of the standard deviation above the mean score are classified as field independent, while participants who scored under a half of the standard deviation below the mean score are classified as field dependent. The rest of the participants whose scores lay in between these two categories are considered as field intermediate.

5.3.4 Field dependence/field independence and academic achievement

Witkin's initial contention about the construct of the FD/FI was the 'neutrality' that suggested that field dependent and field independent subjects are equally well-adapted to meet the demands of their environment (Witkin *et al.*, 1977). Tinajero and Paramo (1997) referred to early studies by Witkin and co-workers which showed there was no link between the FD/FI and overall achievement.

However, Witkin's early finding was contested by many researchers. Dubois and Cohen (1970) found significant correlations between the overall mark in a university admission examination and scores in the FD/FI test. An extensive study by Griffin and Franklin (1996) showed that field independence predicts success at the undergraduate level across many disciplines. In another study, Tinajero and Paramo (1997) also showed that the FD/FI is related to overall academic achievement; the field independent students at secondary school level performed better than the field dependent ones in all of the subjects.

Moreover, many studies in science education indicated that those who are found to be field independent score significantly higher than those who are found to be field dependent in most of the academic fields of chemistry and physics, in mathematics, computer science, and natural sciences at secondary school level as well as at university level (Danili, 2001; Bahar, 1999; Gray, 1997; Alamolhodaei, 1996; Ziane, 1990; Al-Naeme, 1988; El-Banna, 1987). Despite some studies which had shown no correlated results between the FD/FI and performance, but 'in no case have field-dependent subjects been shown to perform better than field-independent subjects' (Tinajero and Paramo, 1998; Davis, 1991).

Reiff (1996) argued that typical instructional environments favour the field independent learners since the desired schooling outcomes closely match to that of the learners' characteristics. Cohen (1969) and Kogan (1976) also expressed that the greater analysis and restructuring ability of the field independent students may favour achievement in the school environment, especially in the areas that require analytical skills and the use of processing strategies based on the organisation and restructuring of information. Frank (1984) reported a significant correlation between the test of the FD/FI and academic performance in proportional reasoning where irrelevant-relevant information was presented, but no significant correlation was found between them when only relevant information was presented.

Therefore, Witkin *et al*. (1977) and Zehavi (1995) suggested that field dependent and field independent learners may produce the same performance when learning materials are well structured and organised. Armstrong (2000) and Tinajero and Paramo (1998) suggested that careful consideration of the methods of assessment, the instructional methodology, and the degree of structuring of teaching materials might improve the field dependent students' performance.

5.3.5 Field dependence/field independence and working memory capacity

Several researchers have attempted studies concerned with the FD/FI in relation to the working memory capacity (Christou, 2001; Al-Naeme, 1988; El-Banna, 1987; Case, 1974; Pascual-Leone, 1970). The results of these studies support the hypothesis that field independent ability is a developmental characteristic and field independent individuals are using their working space memory more efficiently than field dependent individuals.

Furthermore, students who are field independent and with high working memory capacity tend to produce the best performances in academic achievement (Christou, 2001; Al-Naeme, 1988). Among students with the same working memory capacity, their performance declined when the student is more field dependent (Bahar, 1999; El-Banna, 1987). However, It is also worth noting that students with low working memory capacity but who are field independent have a similar performance when compared with those who have high working memory capacity but who are field dependent (Ghani, 2004; Bahar, 1999; Al-Naeme, 1991).

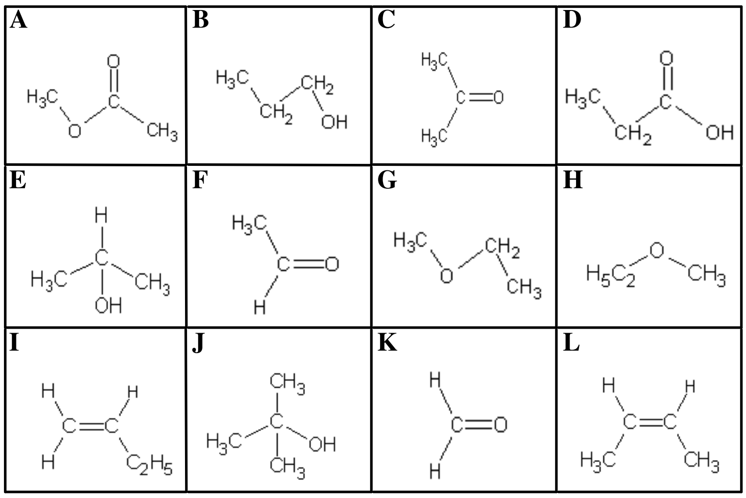
Johnstone *et al*. (1993) explained that those with low working memory capacity but who are field independent are using their limited memory space efficiently for useful processing, because they take only the 'signal' and ignore the 'noise', while those with high working memory capacity but who are field dependent have part of their working memory occupied by irrelevant information because of their field dependent characteristic. Thus, high working memory capacity and field dependent students cannot benefit from their larger working memory space and, therefore, both of them tend to show similar results in the examinations.

5.4 Structural communication grids

The *structural communication grids* (SCG) is a powerful assessment technique (Johnstone, 2003; Bahar and Hansell, 2000). The earliest work was done by Egan (1972) and since then this technique has been used and developed in various schools and disciplines as well as in research by many researchers or research organisations (e.g. Chen, 2004; Hassan, 2003; Johnstone *et al*., 2000; Bahar, 1999; Scottish Exam Board, 1997; Johnstone and Mughol, 1979; Duncan, 1974). They used structural communication grids as an alternative method of diagnostic and summative testing.

In the SCG, the data is presented in the form of numbered grids/boxes (Figure 5-4). The contents of the data can be numbers, words, phrases, pictures, equations, formulas, chemical structures, and others. The data represent the solutions to the questions asked which is laid below the grids. An example from Hassan (2003) illustrates the approach, this one being used with first year undergraduates:

- Look at the boxes below and answer the questions that follow.
  (Boxes may be used as many times as you wish)



Select the box(es) which show the structure of:

(a) An isomer of the compound shown in box G - - - - - - - - - ______________

(b) A secondary alcohol - ______________

(c) An aldehyde (alkanal) - ______________

(d) A compound which reacts with bromine water to form 1,2-dibromobutane - ______________

(e) An ester - ______________

Figure 5-4: An example of the structural communication grids (3 x 4).

Hassan, 2003

SCG questions present an array of information. Respondents are asked in response to a question by considering the content of each box and decide which box or combination of boxes constitutes the most appropriate solution(s) to the question. In answering the questions by selecting the appropriate boxes, a respondent (Johnstone, 1988):

> *...has stamped his structure upon the random boxes of information to communicate his understanding of the material being tested: hence the name 'Structural Communication'...*

In some circumstances, respondents can also be asked to list the responses in a correct logical sequence in order to show their reasoning. The same box may be selected as a part of a response to a series of questions and, if the unit is well structured, it will play a different role in each question.

The appropriate size of the grids can be chosen according to the age of the population using it. For first year of secondary school level, grids with nine boxes (3 x 3) have been found to be appropriate (Johnstone and Ambusaidi, 2001; 2000; Johnstone *et al*., 2000). The larger grids (3 x 4 or 4 x 4) can be used with higher level and the largest grids that was used on undergraduates contain twenty boxes (4 x 5) (Bahar, 1999).

In terms of selecting the boxes, there are four possibilities (Bahar, 1999). To obtain a full score, the student should include all the relevant data only. The student includes most but not all the relevant data and no irrelevant data and this leads to a lesser score. If the student includes some or all relevant data along with some irrelevant data, he/she will get an even smaller score. Finally, the student omits all relevant data and includes irrelevant data only and so gets a negative score or no score. To obtain a score for each question, Egan (1972) suggested a formula:

$$\text{Score} = \frac{\text{The number of relevant data chosen}}{\text{The number of relevant data available}} - \frac{\text{The number of irrelevant data chosen}}{\text{The number of irrelevant data available}}$$

According to this formula, a student's scores range is from +1 to -1. For example, in a nine boxes SCG, suppose that an answer to a question requires three boxes and the student chooses two correct answers plus one irrelevant answer (out of six), thus the score is given: 2/3 – 1/6 = 0.5 (Ghani, 2004).

For insights into conceptual understanding, a structural communication grids is highly recommended. According to Bahar (1999) and Johnstone (1988), applying SCG in the assessment, it could test the ability of learners to recognise examples of a concept from non-examples, to select information which gives a description, sequence information to give a coherent procedure, and to make deductions and inferences from the information given. SCG also can be suitable for learners in self-assessment. It helps them to test relationships within the structure of the concepts in their cognitive structure and enable them to see where linkages are strong and where they are week. In school, educators can have the opportunity to gain insight into a learner's thinking, to see where the misconceptions or mislinkages lie in the learner's mind, and to understand the degree of completeness and interconnectedness in the learner's knowledge in a given topic (Johnstone *et al*., 2000).

Reid (2003) had summarised some of the advantages in using structural communication grids:

- *Guessing is virtually eliminated because the student does not know in advance of knowing how many boxes are required or in which sequence they are required to provide an adequate answer;*
- *The correct responses reveal something of students' insights of conceptual understanding, area of interest, or students' knowledge gaps;*
- *The wrong answers reveal something of students' insights of misunderstandings and misconceptions;*
- *There are several ways to score and credit is also given for partial or incomplete knowledge;*
- *Clear patterns of responses are highly informative;*
- *You can ask many questions using one grid, gaining useful insights into many aspects of some concept or area of interest.*

Furthermore, the flexibility of SCG as an assessment and diagnostic tool is enormous and would lend itself to the production of much effective and systematic examination while at the same time testing many objectives at several levels of complexity. If the test has been well constructed so that each concept is examined from several points of view, the educator is in a position to see weaknesses in learning and teaching. However, there is one drawback, which must be countered. Marking needs careful thought to gain the most powerful insights, especially in the sequencing of questions (Reid, 2003).

5.5 Word association test

A *word association test* (WAT) is one the commonest and oldest methods for investigating cognitive structure in the long-term memory (Bahar, 1999). It can be used as a probe to elicit the associations of a set of concepts in a person's mind (White and Gunstone, 1992), i.e. as a diagnostic tool to measure understanding of concepts and topics and as an assessment tool to detect concept changes between pre-instruction and post-instruction (Bahar, 1999). Also, the order of the response retrieval may reflect a significant part of the structure with and between concepts (Shavelson, 1972) and the degree of overlap of response hierarchies could measure the semantic proximity of the stimulus words (Deese, 1965).

In the word association test, a series of key (stimulus) words, typically about ten, from the topic are selected and subjects are asked to list, for each stimulus word (taken one at a time) as many related terms as possible (usually up to ten words) in a fixed time (30 seconds to one minute). There is an example showed in Figure 5-5 (Ambu-Saidi, 2000).

		Gas
Gas	1.	Hydrogen
Gas	2.	Air
Gas	3.	Element
Gas	4.	Oxygen
Gas	5.	Pressure
Gas	6.	Temperature
Gas	7.	Carbon Dioxide
Gas	8.	Reaction
Gas	9.	Compound
Gas	10.	Car

Figure 5-5: An example of the word association test.

From Ambu-Saidi, 2000

In the WAT, each stimulus word is written at the top of the response and ten times down the side of the page, so that subjects are encouraged to return to the stimulus word after each association in order to minimise the chain effect, in which each response, rather than the key word becomes the stimulus for the next response (Bahar, 1999). The total test time is around five to ten minutes and this is controlled by the examiner.

There are several ways to analyse the response from the WAT, such as the number of responses to each stimulus word, the nature of these responses, and the overlap between responses to pairs of words. The most common method is to measure the number of responses (Shavelson, 1974).

According to White and Gunstone (1992), it is reasonable to assume that the total number of different responses for a word is significant and indicates the individual's understanding of the word, because meaning can be defined as being proportional to the number and complexity of the links which the individual can make to the word. While the learner studies the topic, the key concepts should increase in meaningfulness, and so the average number of responses to each concept should increase (Bahar, 1999; Schaefer, 1979). However, one must be cautious about using the number of responses as a measure of understanding of the given key word, the responses must be relevant and some have restricted marks for those responses which are considered relevant for the area of interest being explored (Al-Qasmi, 2006).

Many studies have been carried out looking at the relationships between cognitive structure of students and their performance in examinations and problem solving tasks. In Johnson's (1967) study, the higher achievers in physics gave more number of associations to the stimulus words than did the low achievers. Johnstone and Moynihan (1985) found that there was a significant positive correlation between the students' performance in WAT and in a chemistry test. The same results also showed on the research of chemistry education of Cachapuz and Maskill (1987).

Moreover, Kempa and Nicholls (1983) investigated the effects of cognitive structure on students' problem solving performance in chemistry and they found that the more branched and networked the knowledge is in a student's mind, the more accessible it is and the more effective it is for problem solving. Their work considered problems of a routine or algorithmic nature. Similar findings were found by Reid and Yang (2002) for more open-ended problems in chemistry while Al-Qasmi (2006) came to parallel findings with her work looking at problem solving in biology. In another study, it was found that, if the relationships did not appear in the association structures from the WAT, students tended not to be able to solve test items which required the concepts relations (Cachapuz and Maskill, 1987).

The word association test can be a useful tool for revealing the type and the number of concepts in the learners' minds along with the links existing between them (Bahar *et al.*, 1999b; Johnstone and Moynihan, 1985). It is simple to prepare and administer; WAT does not take a long time to apply and can be used for large number of students. According to Johnstone and Moynihan (1985), WAT can be used as a tool of teaching, learning, and diagnostic assessment. However, there are still some limitations:

- No decision can be made in the interpretation of cognitive structures as to the connection or otherwise of association since the pupil's reasons for making the association are not known (Kempa and Nicholls, 1983).

- A student may properly associate concepts but there is no guarantee that the student understands their relationships (Stewart, 1979). Nevertheless, Nagy (1983) noted that the changes in achievement after instruction could be considered as the evidence of the growth of cognitive structures.

- In some responses, it may be seen that successive words show a chain of thought. In order to minimise the chain effect, each stimulus word is written at the top and down the side of the page so that subjects are encouraged to return to the key word after each association (Bahar, 1999).

- Teachers may get different types of response to the given stimulus word. It may be nouns and adjectives, word that are associated just because they sound similar or paired opposite, word that are similar in meaning, or ones that are used together, but the student does not know why (Sutton, 1980). To minimize this effect, the situation may be limited by some instruction about acceptable response (Ambu-Saidi, 2000).

5.6 Attitudes measurement

As mentioned in section 2.3 of Chapter two, attitudes express our evaluation of something or someone. Attitudes allow us to make sense of ourselves, the world around us and relationships between us and the world (Reid, 2004). They provide a frame of reference for the individual. They are based on our knowledge, our feelings, and our behaviours and they influence future thinking and behaviour. Thus, attitudes are so important. In education, attitudes may determine how a learner uses his/her knowledge or whether he/she has a motivation to study the subject further, and even in taking it for a future career.

However, attitudes cannot be directly measured, because of their latent construct nature. All attitudes must be inferred by considering the observed stimuli and responses (Figure 2-2). In addition, with current techniques, it is not possible to measure attitudes of individuals with any degree of accuracy. What can be done is to observe change in attitudes or differences in attitudes when comparing two or more groups.

There are several techniques developed for measuring attitudes; self report (questionnaires), partially structured stimuli (similar to projective tests), performance of tasks (congenial material; learned rapidly), observation of overt behaviour, and physiological tests (Cook and Selltiz, 1964). In schools, questionnaires and interviews are practical and useful ways for educational research to explore various aspects of attitudes. Both involve some kind of direct contact with the respondents. With questionnaires, it is easy to collect a large amount of information quickly while, with interviews, the information is often rich and revealing although it often based on a small number of interviews. Cook and Selltiz (1964) noted that all the techiques have their advantages and no one of these methods is perfect and the researcher should not use only one method in the research. However, this idea is not always possible to maintain.

5.6.1 Questionnaire

Oppenhein (1992) described the questionnaire as

> *An important instrument of research, a tool for data collection…it can be considered as set of questions arranged in a certain order and constructed according specially selected rules.*

A well-constructed questionnaire can provide insights into how students think and the way they evaluate situations and experiences (Reid, 2004). It could be composed of closed response questions, open response questions, or a combination of the two. A questionnaire that calls for closed responses provides alternative answers for each question or item, and the respondent is asked to choose from among these answers. A questionnaire that calls for open responses requires that the respondents write out the answer in their own words.

The closed-response format enables the tester to produce summaries of the results quickly and accurately, whereas reading numerous lengthy paragraph responses and then summarizing them is a very time-consuming procedure. However, open-end questions do not limit the range of possible answers as do closed-response questions. People can express their exact opinion in an open-end response whereas if asked to simply check items they may feel that they have been forced into responses that do not exactly match their attitudes. Moreover, open-ended questions may produce outcomes that were unanticipated when constructing the questionnaire (Henderson *et al*., 1978). Most questionnaires include some open-end items, therefore, to permit some ventilation of feelings and to obtain some unprompted responses. It is generally best, however, to use closed-response formats for most of the questionnaires (Henderson *et al*., 1978).

There are several kinds of question formats that can be used in the construction of closed-response questionnaires, such as checklists, two-way questions, multiple-choice questions, and ranking scales. Moreover, the *Likert* approach (Likert, 1932) and the *semantic differential* approach (Osgood *et al*., 1957) also have been widely used in the educational research for many years (Reid, 2006). Each of these is now discussed.

1. *Likert method*:

A Likert scale is a type of psychometric response scale often used in attitude measurement. It is a bipolar scaling method, measuring either positive or negative responses to a statement or question. The respondent is asked to indicate his/her degree of agreement with a statement or any kind of subjective or objective evaluation of the statement. Usually a five-point scale is used where:

1 = Strongly unfavorable to the concept.
2 = Somewhat unfavorable to the concept.
3 = Undecided/Uncertain.
4 = Somewhat favorable to the concept.
5 = Strongly favorable to the concept.

There is a variety of possible response scales (seven-point or nine-point etc.). All of these odd-numbered scales have a middle value (often labeled *neutral* or *undecided*). It is also possible to use a forced-choice response scale with an even number of responses. In this situation, the respondent is forced to decide whether they lean more towards the '*agree*' or '*disagree'* end of the scale for each item.

After the questionnaire is completed, each item may be analyzed separately or item responses may be summed to create a score for a group of items. Because the final score for the respondent on the scale is the sum of their ratings for all of the items, Likert scales are often called summative scales. On some scales, items are reversed in meaning from the overall direction of the scale. Thus the response value for each of these items needs to be reversed before summing for the total. That is, if the respondent gave a 1, examiner makes it a 5; if he/she gave a 2 examiner makes it a 4, 3 = 3, 4 = 2, and 5 = 1.

This method assumes that the spacing between the points on the scale in each question are the same and that it is valid to add up scores between items simply on the basis of correlation. However, it is highly possible to have two items which are correlated but which are asking completely different questions. Thus, each item should be analyzed separately. The responses elicited may be coded e.g. 1-2-3-4-5, but this remains just a coding. The data collected are ordinal. It makes no sense to add a response of agree (coded as 2) to a response of disagree (coded as 4) to get a 'mean' response of 3.

According to Tittle and Hill (1967), the Likert scale is the most widely used method of scaling in the social sciences today. This is because they are relatively simple to construct, easy for respondents to complete and because they tend to be more reliable than other scales with the same number of items and easy to analyse statistically. Nonetheless, the common method of analyzing is open to wide criticism and this has been discussed fully in Reid (2006). It is much safer and more illuminating to analyse each question separately and this method was adopted here.

2. *Osgood's method of the semantic differential*:

Osgood's semantic differential is a type of a rating scale designed to measure the connotative meaning of concepts. It was not originally developed for attitude measurement but has been proved to be a useful measure of attitudes (Rodefeld, 1967; Barclay and Thumin, 1963; Osgood *et al.*, 1957).

The respondent is asked to choose where his/her position lies, on a scale between two bipolar words, or a range of words or numbers ranging across a bipolar position (Figure 5-6). A scale like this one measures directionality of a reaction (e.g. good versus bad) and also intensity (slight through extreme). Ratings are combined in various ways to describe and analyse the person's feelings.

• What are your opinions about your laboratory experiences in chemistry?

Tick ONE box on each line.

Useful	☐	☐	☐	☐	☐	☐	Useless
Not helpful	☐	☐	☐	☐	☐	☐	Helpful
Understandable	☐	☐	☐	☐	☐	☐	Not understandable
Satisfying	☐	☐	☐	☐	☐	☐	Not satisfying
Boring	☐	☐	☐	☐	☐	☐	Interesting
Well organised	☐	☐	☐	☐	☐	☐	Not well organised
The best part of chemistry	☐	☐	☐	☐	☐	☐	The worst part of chemistry
Not enjoyable	☐	☐	☐	☐	☐	☐	Enjoyable

Figure 5-6: An example of the semantic differential question.

From Reid, 2004

Osgood *et al*. (1957) noted that mainly three underlying dimensions or factors are involved in judging concepts. These are evaluation which consist of evaluation statement (e.g. good-bad), potency which measure power and potency of judgment connotation (e.g. strong-week), and activity which measures judgements (e.g. fast-slow). This factorial structure makes intuitive sense and three factors thus encompass a detailed descriptive system of the connotative meaning of abstract concepts.

The semantic differential is a simple, economical means for obtaining data on people's reactions. It is easy to construct, and respondents can answer large number of questions quickly. With adaptations, such scales can be used with adults or children, persons from all walks of life, and persons from any culture. Moreover, the semantic differential has been found to be reliable (Osgood *et al*., 1969) and the validity appears to be high, based on its high correlation with measurements on other attitude scales, like Likert, Thurstone, and Guttman (Tittle and Hill, 1967; Nickols and Shaw, 1964; Brunton, 1961).

Reid (2004) provided suggestions to help develop an effective questionnaire. These suggestions are organised according to the following steps:

1. *Write down as precisely as possible what you are trying to find out;*
2. *Decide what types of questions would be helpful;*
3. *Be creative and write down as many ideas for questions as you can;*
4. *Select what seem the most appropriate from your list - keep more than you need;*
5. *Keep the English simple and straightforward, avoid double negatives, keep negatives to a reasonable number, look for ambiguities, watch for double questions;*
6. *Find a critical friend to comment on your suggested questions;*
7. *Pick the best, most appropriate and relevant questions, thinking of time available;*
8. *Layout is everything!*
9. *Try your questionnaire out on a small sample of students (e.g. a tutorial group) - ask for comments, criticisms. Check time required.*

10. *Make modifications and only then apply to larger group;*
11. *Analyse each question on its own.*

5.6.2 Interview

Interview is a very powerful tool to gain insights into people's attitudes. There are two types of interview:

- Exploratory interview: Spontaneous conversation
- Standardised interview: A prepared set of questions

A large amount of information can be produced by talking to respondents about their experience or feelings. Also the interview helps the respondent to avoid vagueness and misunderstanding of the questions. It allows the researcher to observe the order of answers and their emotional power. Furthermore, interviews can be used to check the validity of the data obtained from questionnaires. Nevertheless, undertaking interviews has some disadvantages:

- Interviews take considerable time both for respondents and the researcher;
- It is difficult to translate all the information from interviews into a neat summary;
- There is the possibility that the interviewer may influence the way the interview is conducted and the way results are interpreted.

It is possible to use questionnaires to explore issues raised by exploratory interviews. Equally, it is possible to validate questionnaires by use the short interviews. Therefore, for reliable and valid data, it is recommended to use a combination of questionnaire and interview.

5.7 Validity and reliability of the research instruments

Validity and reliability are considered two of the most important characteristics of a research instrument whether in the form of a test, an interview, an observation or a questionnaire (Ary *et al.*, 2001; Mason and Bramble, 1989). Validity refers to the degree to which an instrument actually measures what it is intended to measure (Mason and Bramble, 1989). According to Reid (2003), validity asks the questions: ‘are we measuring what we think are measuring?’

However, there is never any certainty that validity is achieved totally in research (Reid, 2003). Nonetheless, steps must be taken to aim for validity of the instrument. In order to ascertain this, some kind of criterion external to the instrument used is needed, such as relying on the views of experts (face validity) or some separate source of evidence (concurrent validity) (Reid, 2003).

Reliability refers to the degree to which an instrument is consistent in measuring whatever it is purported to measure. It is the tendency of the instrument to produce similar scores or values when applied to the same individuals and under the same conditions but at a different time. An instrument might be reliable without being valid, but it cannot be valid if it is not reliable (Ary *et al.*, 2001). Methods used to estimate the reliability of an instrument are either based on correlational procedures (e.g. test-retest, split-half) or on the proportion of respondents who get the items right or wrong.

However, most of the methods merely give evidence about internal consistency of an instrument whether items in that instrument only measure the same thing. If the items are designed to measure many different things, consistency is, therefore, meaningless (Reid, 2003). Nevertheless, if the instrument is designed carefully to avoid ambiguity, like the items are moderately difficult and the length of the instrument is reasonable, it is very likely that the measurements will be reliable (Reid, 2003).

Chapter Six

Results and Discussions I

6.1 Introduction

In the previous chapters, the study has considered the literature on genetics of learning. Issues are raised about how the psychological factors affect learning and how the nature of the genetics knowledge and the preconceptions cause the difficulties and problems in learning.

The first stage of the research in this study looks into the learners' preconceptions about genetics in more detail to obtain an insight into the basic underpinning ideas that the learners hold when they move to their first formal genetics course. The importance of previous knowledge has been demonstrated by Ausubel *et al.* (1978) and shown to be a powerful influence by many researchers, such as Hassan *et al.* (2003), Sirhan and Reid (2001), Stewart (1982), and Cho *et al.* (1985). However, most of the studies had looked at either high school or university level or other science subjects, like chemistry or physics.

The aim here is to find out what ideas are well grasped by the learners as they approach their first formal genetics course in order to explore where they hold confusions, misconceptions or even show a lack of basic knowledge. These alternative ideas could be a consequence of previous instruction on other biology topics other subjects or informal 'common-sense' knowledge from everyday experience and language.

Firstly, the approaches used are described along with detail about the sample of learners chosen. The results obtained are then discussed.

6.2 The study sample

The study looked at the first year of public junior high school students (aged 13 approximately) in Taiwan. A total of 141 students from five classes were used; boys are 78 and girls are 63.

The schools were selected to give a good cross section which would be typical of the Taiwanese population at this age. It has to be noted that there is a considerable degree of central control over the curriculum and its presentation in Taiwan, and schools tend to conduct teaching in very similar ways.

Genetics does not feature in the science or biology syllabuses of Taiwan until the first year of junior high school which is part of the compulsory education. As mentioned in Chapter two, the compulsory education is nine years from primary school to junior high school (aged 6-15). In the meantime, students have to take all the same subjects together. After compulsory education, genetics only features in the curriculum for the senior high school students or higher who are taking biology as a separate subject. Thus, the first year of junior high school is the critical moment for preparing these future citizens in Taiwan to face this area of biological knowledge. Many will never receive any formal instruction in genetics again.

6.3 Preparing the study instrument

The genetics context in Taiwanese junior high school textbooks (which schools follow closely) can be divided into four parts after analysis (Figure 6-1):

- The first part is basic knowledge, which introduces genetic terms, such as DNA, chromosome, gene, and traits.

- The second part is theory of genetics; Mendelism. It starts from how the father of genetics, Gregor Mendel, had founded the laws of inheritance. Then definition of genotype/phenotype, the concepts and principles of Mendelian genetics laws, and how to predict and calculate the probabilities of inheritance by the method of Punnett square are presented.

- The third part is human inheritance. In this section, learners will understand the trait inheritance which includes the single-factor inheritance and multi-factor inheritance, the sex inheritance which introduces sex chromosomes and sex determination, and the inherited human diseases (somatic/sex-linked diseases) and genetic counselling.

- The last part is applications of genetics, and biotechnology and genetic engineering are included.

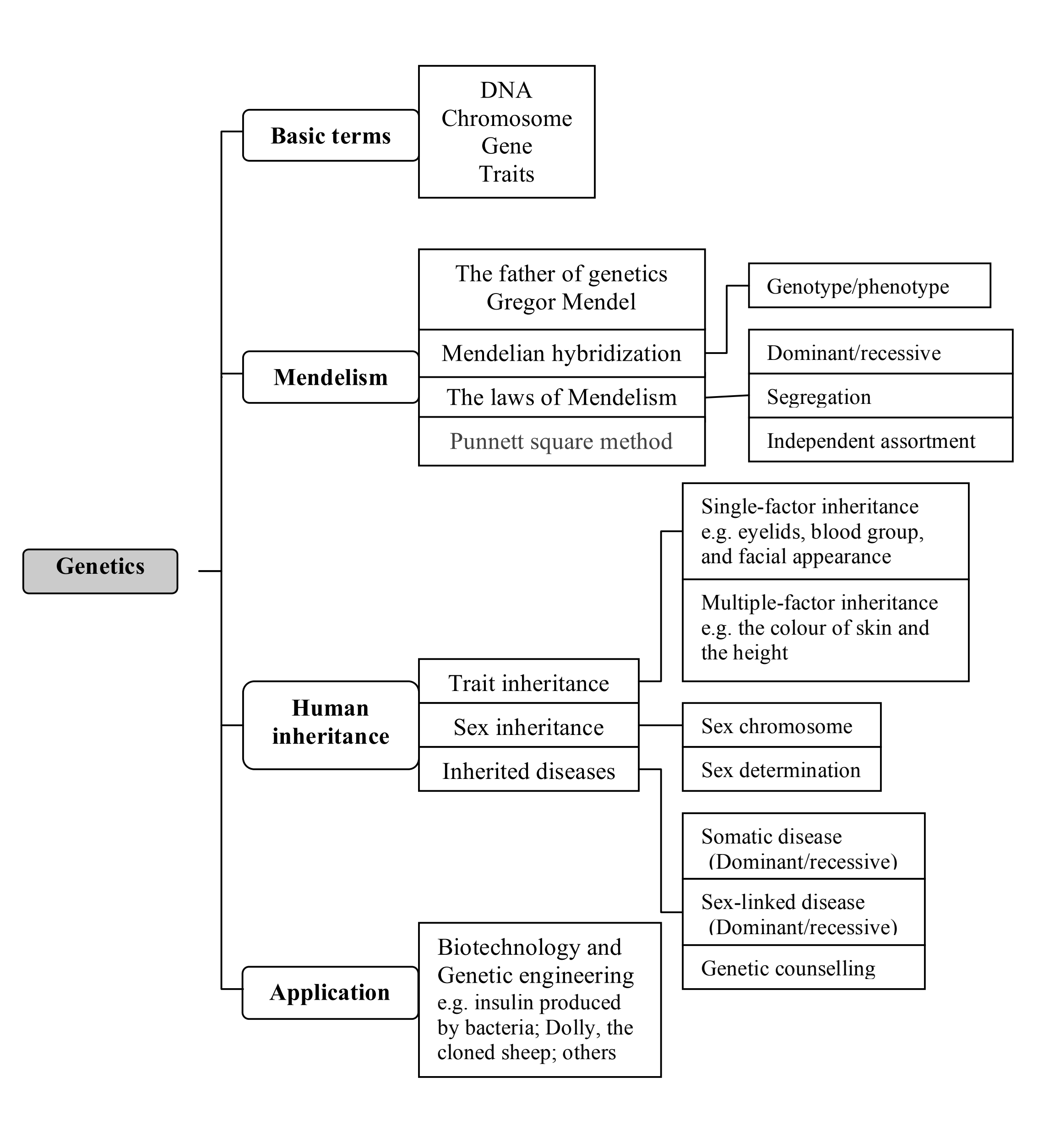


Figure 6-1: Genetics content in Taiwanese junior high school textbooks.

Analysing the contexts of genetics further, it is considered that several foundational concepts could be essential for reaching students' acquisition of meaningful understanding of inheritance. They are structure and function of cells and its organelles, cell divisions (mitosis and meiosis) and reproduction, and basic mathematical requirements, especially in the concept of probability (Chattopadhyay, 2005; Lewis *et al.*, 2000a; Pashley, 1994a; b).

Thus, if students do not understand the basic nature of the way cells are constituted and the way the components of cells function, then any attempt to make sense of genetics will be very difficult. Equally, students need to have a clear grasp of the whole processes of cell divisions and reproduction, because any understanding of genetics builds on this understanding of genes/allele arrangement and segregation. Finally, the whole basis of genetics rests on the ideas inherent in probability. While previous biology courses have covered the areas of cells and their components as well as the nature of cell divisions and reproduction, there is only a little teaching ever given on probability and that comes from the primary stage.

Therefore, the research design of the genetics pre-knowledge test used in this study is based on these foundational concepts. This test was designed by using structural communication grids as a diagnostic testing method. The strength of the SCG technique is in exploring incomplete answers and looking closely at patterns of wrong answers. The correct responses reveal something of the grasp of the fundamental concepts, but incomplete responses (the missing answers) reveal something of students' knowledge gaps. Also, the wrong answers offered by many students reveal something of misunderstanding or misconceptions (Reid, 2003).

Because the target of the research is junior high school students, the grid of nine boxes was chosen. The study instrument is in Chinese language and an English version is shown in Figure 6-2. There are three parts in this pre-knowledge test of genetics and each part tests different aspects which are considered important and essential for junior high school students in order to find out students underpinning ideas before they learn genetics:

- The structure, location, and function of inheritance information in the cell;
- The chromosomes' behaviour in the cell divisions and the differences of the processes, purposes, and products between mitosis and meiosis; and
- The concept of probability laws and its calculation.

Pre-knowledge Test of Genetics

Name: ____________________ Sex: ☐ Boy ☐ Girl

This is a test of your common sense about genetics.
There are three parts. At the beginning of every part have nine boxes, which are labelled English letters from A to I on the upper left side.
Please select the box(es) to answer the following questions - use English letters to show your answers. Boxes may be used as many times as you wish.

The results of this test will not affect your schoolwork in any way.
Thank you very much!
Centre for Science Education, University of Glasgow, Scotland.

Part 1:

A DNA	**B** Nucleus	**C** Mitochondria
D Chromosome	**E** Cell	**F** Cell membrane
G Gene	**H** Protein	**I** RNA

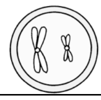
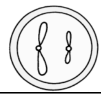
Select the box(es) which are true:

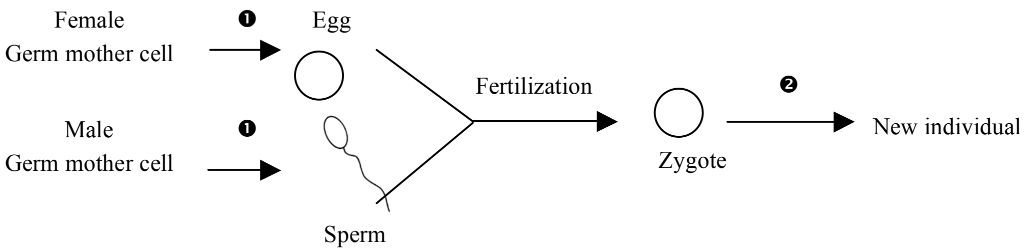
(1) In the human body, they usually exist as pairs. - ____________
(2) The functional and physical unit of hereditary passed from parent to offspring. - ____________
(3) The molecules contain the genetic instructions for development and functioning of living organisms and can be passed from one generation to the next. - - - - - - ____________
(4) We can find these in the nucleus. - ____________
(5) We can find these on/in the chromosome. - ____________
(6) The structural and functional unit of all living organisms and is called the 'building block of life'. - ____________

Figure 6-2: Pre-knowledge test of genetics.

Continued

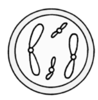
Part 2: Look at the boxes below and select the box(es) to answer the following questions.
(Boxes may be used as many times as you wish. - use English letters on the upper left side of the box to show your answers.)

A Mitosis	**B** Pair	**C** 
D Meiosis	**E** Non-pair	**F** 
G 	**H** 	**I** 



(1) Which box(es) show the process "❶" ? - ____________
(2) Which box(es) show the process "❷" ? - ____________

For the following questions, if there is an organism which has four chromosomes (Like the figure on the right hand side):



(3) Which box(es) show the situation of chromosomes of its gametes? - - - - - - - - - ____________
(4) Which box(es) show the situation of chromosomes of its zygote? - - - - - - - - - - ____________
(5) If the zygote does cell division once, which box(es) show the situation of chromosomes in the daughter cell? - ____________
(6) The organism scraped its skin, but the skin cells had recovered several days later. Which box(es) show the situation of chromosomes in the new cells? - - - - ____________

Part 3: Look at the boxes below and select the box(es) to answer the following questions.
(Boxes may be used as many times as you wish. - use English letters on the upper left side of the box to show your answers.)

A 0	**B** 3	**C** 1/2
D 1	**E** 25%	**F** 1/4
G 2	**H** 50%	**I** 3/4

Figure 6-2: Pre-knowledge test of genetics.

Continued

We know that the chance of a couple having a boy and a girl are the same.
If a couple decided to have only one baby:

(1) What is the probability that they have a boy? - ____________

If a couple decided to have two babies:

(2) How many possibilities of babies gender can happen? - - - - - - - - - - - - - - - - - ____________
(3) What is the probability that they both are boys? - ____________
(4) What is the probability that they have one boy and one girl? - - - - - - - - - - - - - ____________
(5) If the first child is a boy, what is the probability that their second child is a boy? - ____________

Figure 6-2: Pre-knowledge test of genetics.

It should be noted that, before giving the test, it was checked by several experts; two reputable researchers in science education and three experienced biology teachers in Taiwan. For pre-testing it, a sample of 17 students (aged 13-16) from Glasgow Chinese School Stow College was selected (a weekend language course for Scottish-born Chinese children; those selected in this study have come from different secondary schools around Glasgow). Students' responses were examined and a few of them were interviewed in order to clarify their ideas.

After analysis, the first test was modified and applied to the whole sample (Figure 6-2). The test was completed in April, 2004 after students were taught the chapter of reproduction and before they received tuition on the genetics, with 15-20 minutes being found to be an adequate time. It aimed to test the grasp of underlying ideas which are fundamental for learning genetics. This is the strength of structural communication grids in that it offers insights into the conceptual understanding of ideas tested.

6.4 Methods of analysis

The SCG test was analysed in two ways. Firstly, each student's response to each question was converted into a code and the data stored in a spreadsheet. Using the spreadsheet, the codes were used to score the student' performance in separating relevant from irrelevant and then generate a total mark for each topic. This used the method of scoring developed by Egan (1972) and widely used (e.g. Danili, 2004; Ghani, 2004; Johnstone and Ambusaidi, 2001; Ambusaidi, 2000; Bahar, 1999):

$$\text{Score} = \frac{\text{Number of correct box(es) chosen}}{\text{Number of correct box(es) available}} - \frac{\text{Number of incorrect box(es) chosen}}{\text{Number of incorrect box(es) available}}$$

According to this formula, a student's score ranges from +1 to -1. This can then be multiplied by some factor to give the student a recognisable score (Johnstone and Ambusaidi, 2001). For example, add one to raw score (to get rid of the negative) and multiply by 5. The score would then range from 10 to 0 (Danili, 2004; Bahar, 1999). In this study, one was added to the scores from the test, this being multiplied by 50: the final range of scores is from 100 to 0. It is used to score the total mark for each topic as well as the total final mark of this test.

Subsequently, the study had looked at responses to each question individually. To count the numbers of students under each response can give a picture of how students performed in each question and where the problems lie in order to gain maximum insight into the strength and weakness of underlying concepts of students. Here, the students' responses for each section of each question were discussed in turn.

6.5 Results and discussions

The results obtained from the diagnostic use of SCG test for the pre-knowledge test of genetics are analysed and discussed. Firstly, the data of descriptive statistics are analysed in general, and then the students' responses for each section of each question are presented as numbers and percentages in turn.

It has to be mentioned that, for simplicity and clarity, all data are presented as percentages, the answer grids used are shown for each part, and any choices less than seven (5%) are not shown on the tables. In addition, the relationships of the data with other crucial factors will be presented in the next chapter.

6.5.1 The data of descriptive statistics from the pre-knowledge test of genetics

The pre-knowledge test of genetics was developed based closely on the content of what was taught at earlier stages as well as the standards of knowledge and understanding expected of junior high school students in Taiwan. It is found that students' average in the test is 38.9 and the standard deviation is 15.0 (Table 6-1). This low result might indicate that students' prior knowledge for genetics is generally poor and that they even have many alternative views. However, the test may simply have been too demanding. Based on the views of some experienced researchers and educators about the test, this latter factor could be taken out.

Table 6-1: The descriptive statistics data of the pre-knowledge test of genetics (N=141).

Test	Test target	Mean	S.D.
Part 1	Concept of inheritance information	41.9	21.7
Part 2	Understanding of cell divisions	28.5	21.0
Part 3	Principle of probability laws	46.2	20.7
Total test	Pre-knowledge of genetics	38.9	15.0

Looking at the general data, it is assumed that the three parts of the test were of appropriate difficulty. Among the three parts of the test, the students' understanding about cell divisions is shown to be the least good and understanding of the meaning of probability is relatively better. It is clear that the students have the greatest problems with understanding the cell divisions.

6.5.2 Part 1 of the test: the structure, location, and function of inheritance information in the cell

The questions of this part tested students about how they grasp the concepts of inheritance information and the ideas relate to the location and relationships of inheritance information.

A DNA	**B** Nucleus	**C** Mitochondria
D Chromosome	**E** Cell	**F** Cell membrane
G Gene	**H** Protein	**I** RNA

Table 6-2: The responses of students to part 1, question 1 of the pre-knowledge test of genetics.

1-1: In the human body, they usually exist as pairs.	N=141	
Response (Correct = D and G)	**No.**	**%**
Both correct answers (chromosome and gene)	2	1.4
D chosen only (chromosome)	67	47.5
G chosen only (gene)	9	6.4
Both correct answer with one wrong answer	1	0.7
One correct answer with wrong answer(s)	15	10.6
D chosen (chromosome)	78	55.3
G chosen (gene)	19	13.5
E chosen (cell)	19	13.5
A chosen (DNA)	18	12.8
C chosen (mitochondria)	13	9.2
B chosen (nucleus)	12	8.5
Average score = 49.9		

It is known that the concept of pairs is very important in genetics which affect the understanding of cell divisions, gamete formation, trait and sex inheritance, the laws of Mendelian genetics, and sexual and asexual reproduction etc.

The results show that 55.3% of students knew that chromosomes usually exist as pairs in the cells, but many of them (41.8%) omitted G (gene). Perhaps, this is because of the way textbooks often show chromosomes as microscopic figures of chromosomes pairs. On the other hand, gene is more abstract concept in that, unlike a chromosome, it cannot be seen using a microscope. In addition, an English letter is often used as a code name to represent the gene.

Table 6-3: The responses of students to part 1, question 2 of the pre-knowledge test of genetics.		
1-2: The functional and physical unit of inheritance passed from parent to offspring.	N=141	
Response (Correct = G)	**No.**	**%**
Correct answer chosen (gene)	33	23.4
G chosen (gene) with wrong answer(s)	25	17.7
A chosen (DNA)	60	42.6
D chosen (chromosome)	34	24.1
B chosen (nucleus)	16	11.3
E chosen (cell)	10	7.1
Average score = 39.7		

While 23.4% of students chose the correct answer, it is important to note that, many of students were confused about the difference between gene and DNA, which are the functional unit and the structural unit of genetic information respectively. The top two of the most common wrong answers appeared to be DNA and chromosome, which are highly related to inheritance. It showed that students seem to be familiar with gene, DNA, and chromosome, but they are uncertain and confused with the definitions and the difference among them. Indeed, this situation had also been found among high school students, undergraduates, and even biology teachers (e.g. Knippels *et al*., 2000; Bahar, 1999; Cho *et al*., 1985; Steward, 1982a).

Table 6-4: The responses of students to part 1, question 3 of the pre-knowledge test of genetics.		
1-3: The molecules contain the genetic instructions for the development and functioning of living organisms and can be passed from one generation to the next.	N=141	
Response (Correct = A)	**No.**	**%**
Correct answer chosen (DNA)	32	22.7
A chosen (DNA) with wrong answer(s)	18	12.8
G chosen (gene)	64	45.4
D chosen (chromosome)	21	14.9
B chosen (nucleus)	18	12.8
E chosen (cell)	9	6.4
Average score = 40.5		

Similar to question 1-2, there is a confusion among DNA, gene, and chromosome, which is consistent with the results from the small group discussions by Wood-Robinson (2000) and Lewis *et al*. (2000a; b; c). The results suggested that these three terms are highly connected in students' minds, but are not totally understood.

Table 6-5: The responses of students to part 1, question 4 of the pre-knowledge test of genetics.

1-4: We can find these in the nucleus.	N=141	
Response (Correct = A, D, and G)	**No.**	**%**
All correct answers chosen (DNA, chromosome, and gene)	6	4.3
Two correct answers chosen	11	7.8
One correct answer chosen	54	38.3
D chosen (chromosome)	41	29.1
A chosen (DNA)	35	24.8
F chosen (cell membrane)	24	17.0
E chosen (cell)	21	14.9
B chosen (nucleus)	18	12.8
G chosen (gene)	18	12.8
C chosen (mitochondria)	11	7.8
I chosen (RNA)	9	8.5
Average score = 36.3		

Around one quarter of the students (29.1% and 24.8%) identified that chromosomes or DNA can be found in the nucleus while only 12.8% of students selected the answer, gene. The students were less clear about the location of gene than chromosomes and DNA. Surprisingly, 17.0% of sample chose cell membrane to be in the nucleus; 14.9% chose cell and 12.8% chose nucleus itself. The answers illustrated that students are lacking in basic knowledge and many misconceptions and confusions about the cell structure may be occurring.

Table 6-6: The responses of students to part 1, question 5 of the pre-knowledge test of genetics.

1-5: We can find these on/in the chromosome.	N=141	
Response (Correct = A, G and H)	**No.**	**%**
All correct answers (DNA, gene, and protein)	2	1.4
Two correct answers chosen	7	5.0
One correct answer chosen	67	47.5
A chosen (DNA)	44	31.2
G chosen (gene)	23	16.3
B chosen (nucleus)	20	14.2
H chosen (protein)	20	14.2
D chosen (chromosome)	14	9.9
F chosen (cell membrane)	13	9.2
I chosen (RNA)	12	8.5
C chosen (mitochondria)	9	6.4
Average score = 37.1		

A chromosome constitutes a physically organized form of DNA, which contains many genes, and includes the DNA-bound proteins, which serve to package and manage the DNA in a cell. One third of students responsed that DNA could be found on/in the chromosome, but only 16.3% of responses explicitly located gene on/in the chromosome. Again, students' concept about gene is quite weak. Evidence from a number of sources also suggest widespread confusion between gene and chromosome and a lack of awareness of the relationship between gene and chromosome (Chattopadhyay, 2005; Lewis and Wood-Robinson, 2000; Lewis *et al*., 2000b; Marbach-Ad and Stavy, 2000; Wood-Robinson *et al*., 2000; Ramorogo and Wood-Robinson, 1995; Kindfield, 1991). All results showed that the answer 'gene' are omitted easily. It is understandable that students tend to ignore the unknown/less understanding answer(s) when they response the test.

On the other hand, it is worth noting that 14.2% of students chose that the nucleus can be found in the chromosome. Perhaps this is because it is often mentioned that chromsomes are found in the nucleus: students have made the connection between chromosomes and the nucleus but have made the connection in a reverse direction.

Table 6-7: The responses of students to part 1, question 6 of the pre-knowledge test of genetics.

1-6: The structural and functional unit of all living organisms and is called the "building block of life".	N=141	
Response (Correct = E)	**No.**	**%**
Correct answer chosen (cell)	62	44.0
E chosen (cell) with wrong answer(s)	8	5.7
I chosen (RNA)	16	11.3
A chosen (DNA)	16	11.3
G chosen (gene)	13	9.2
D chosen (chromosome)	10	7.1
H chosen (protein)	10	7.1
B chosen (nucleus)	8	5.7
Average score = 47.8		

This revealed that 44.0% of students grasped the basic concept of the cells. The outcomes were higher than other questions of part one. It is apparent that a minority of the sample had some problems with the concept. While the cell is always regarded as the ‘building bricks’ of living systems, DNA can be considered as the ‘blueprint’. Clearly, there is the confusion in the minds of the pupils, perhaps even the confusion over language.

6.5.3 Part 2 of the test: the chromosomes behaviour in the cell divisions and the differences of the processes, purposes, and products between mitosis and meiosis

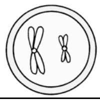
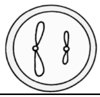
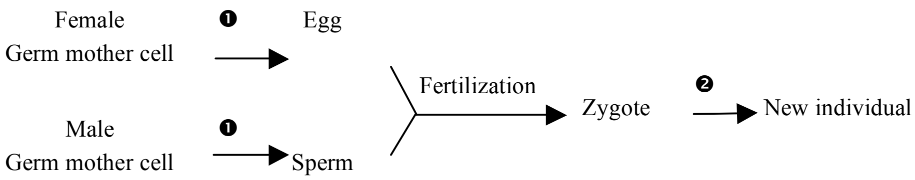
A Mitosis	**B** Pair	**C** 
D Meiosis	**E** Non-pair	**F** 
G 	**H** 	**I** 

Table 6-8: The responses of students to part 2, question 1 and 2 of the pre-knowledge test of genetics.



2-1: Which box(es) show the process "❶" ?	N=141	
Response (Correct = D)	**No.**	**%**
Correct answer chosen	45	31.9
D with wrong answer(s)	13	9.2
A chosen	31	22.0
B chosen	23	16.3
F chosen	19	13.5
E chosen	14	9.9
C chosen	10	7.1
I chosen	9	6.4
Average score = 40.5		

2-2: Which box(es) show the process "❷" ?	N=141	
Response (Correct = A)	**No.**	**%**
Correct answer chosen	45	31.9
A with wrong answer(s)	14	9.9
D chosen	33	23.4
E chosen	20	14.2
B chosen	13	9.2
F chosen	9	6.4
G chosen	8	5.7
C chosen	7	5.0
Average score = 41.2		

As the results from the question 2-1, there are 45 students (31.9%) whose answer was correct, as well as the results from the question 2-2. Checking both questions, it was found that 43 students (30.5%) obtained the correct answers in both question 2-1 and 2-2. Because the test was used not long after the students had completed their studies on reproduction, a higher performance might have been expected. On the other hand, it should be considered more for the word pair question that some of correct responses might be false, which were chosen correctly by luck. This might be a reason to explain the high performance in these questions.

However, a number of response patterns revealed considerable confusion. It was found that 25 students (17.7%) chose the reverse answers from the right answers of two questions. Also, 22% of the sample picked out mitosis in the question 2-1 when the answer should be meiosis and 23.4% of the sample picked out meiosis in the question 2-2 when the answer should be mitosis. Findings illustrated that many students are still confused about mitosis and meiosis and even cannot distinguish them. As mentioned in Chapter three, this confusion over word pairs which look or sound alike had been identified as a source of confusion (Cassels and Johnstone, 1978). Bahar *et al*. (1999a) also indicated that a main source of difficulties students experience with Mendelian genetics might be the difficulties in understanding mitosis and meiosis.

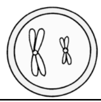
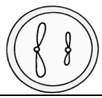
A Mitosis	**B** Pair	**C** 
D Meiosis	**E** Non-pair	**F** 
G 	**H** 	**I** 

Table 6-9: The responses of students to part 2, question 3, 4 and 5 of the pre-knowledge test of genetics.

2-3: If there is an organism whith four chromosomes, which box(es) show the situation of chromosomes of its gametes?	N=141		2-4: Which box(es) show the situation of chromosomes of its zygote?	N=141		2-5: If the zygote does cell division once, which box(es) show the situation of chromosomes in the daughter cell?	N=141	
Response (Correct = E and F)	**No.**	**%**	**Response (Correct = B and H)**	**No.**	**%**	**Response (Correct = B and H)**	**No.**	**%**
Both correct answers	2	1.4	Both correct answers	1	0.7	Both correct answers	0	0
E chosen	9	6.4	B chosen	12	8.5	B chosen	8	5.7
F chosen	37	26.2	H chosen	24	17.0	H chosen	22	15.6
E with wrong answer(s)	2	1.4	B with wrong answer(s)	4	2.8	B with wrong answer(s)	3	2.1
F with wrong answer(s)	5	3.5	H with wrong answer(s)	4	2.8	H with wrong answer(s)	6	4.3
H chosen	34	24.1	C chosen	34	24.1	G chosen	35	24.8
C chosen	19	13.5	G chosen	23	16.3	C chosen	24	17.0
G chosen	18	12.8	F chosen	22	15.6	F chosen	21	14.9
B chosen	15	10.6	A chosen	12	8.5	A chosen	15	10.6
A chosen	11	7.8	E chosen	10	7.1	D chosen	14	9.9
D chosen	7	5.0	I chosen	9	6.4	E chosen	10	7.1
Average score = 29.1			Average score = 23.6			Average score = 20.3		

Question 2-3, 2-4, and 2-5 examined the understanding about the concepts of meiosis, fertilization, and mitosis separately. It showed that many students seem to be unaware of the nature of the difference between mitosis and meiosis. Students were easy to mix up the concepts/results of mitosis and meiosis (answer F and answer H). Also, students performances of this part in school are usually low. It may because the terms of mitosis and meiosis are similar, the process of both cell divisions are similar, the concepts are abstract, and many technical terms are involved (such as, replicating, dividing, copying, splitting, multiplying, and sharing) (Lewis *et al.*, 2000a; Lewis and Wood-Robinson, 2000). These could appear contradictory and cause the learning difficulties in the cell divisions, and then affect the genetics learning later.

Otherwise, when one right answer was chosen, it was usually B/E which was omitted. Perhaps, pictures of chromosomes are easier to grasp. Quite a few of sample picked out G and C. Perhaps, the chromosomes are duplicated in the answers and duplication is an important process in both cell divisions. If students do not have proper concept of the cell divisions, such mistakes can be made.

Besides, the responses of question 2-5 showed that the percentage of students who got either both correct answers or one correct answer is lower than question 2-3 and 2-4. It may be because the question is getting more complex: in question 2-3, the question asks about the concept of meiosis and in question 2-4, students have to judge the situation of gametes, and then think about the result of fertilization. In question 2-5, students have to think what kind of the cell division is first, and then judge the situation of chromosomes in the cell. This involves a little more than recall for it needs ideas to be sequenced and reflects what really happens in the living organisms.

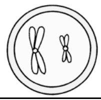
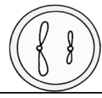
A Mitosis	**B** Pair	**C** 
D Meiosis	**E** Non-pair	**F** 
G 	**H** 	**I** 

Table 6-10: The responses of students to part 2, question 6 of the pre-knowledge test of genetics.

2-6: The organism scraped its skin, but the skin cells had recovered several days later. Which box(es) show the situation of chromosomes in the new cells?	N=141	
Response (Correct = B and H)	**No.**	**%**
Both correct answers	1	0.7
B chosen	8	5.7
H chosen	18	12.8
B chosen with wrong answer(s)	4	2.8
H chosen with wrong answer(s)	2	1.4
A chosen	33	23.4
G chosen	21	14.9
C chosen	21	14.9
D chosen	18	12.8
F chosen	18	12.8
Average score = 17.4		

Again, because of the complexity of the question, the average score is low. From Table 6-11, it can be seen that 23.4% of students selected A, mitosis, which is the way that somatic cells normally divide and not the way for the production of eggs and sperms. However, the question asked for the situation of chromosomes rather than the way of cell divisions. This suggests that students know certain answers by memory but do not really understand or think about the question/answer.

6.5.4 Part 3 of the test: The concept of probability laws and its calculation

A 0	**B** 3	**C** 1/2
D 1	**E** 25%	**F** 1/4
G 2	**H** 50%	**I** 3/4

Table 6-11: The responses of students to part 3, question 1 of the pre-knowledge test of genetics.

3-1: We know that the chance of a couple having a boy and a girl are the same. If a couple decided to have only <u>one</u> baby: What is the probability that they have a boy?	N=141	
Response (Correct = C and H)	**No.**	**%**
Both correct answers chosen (1/2, 50%)	37	26.2
C chosen (1/2)	22	15.6
H chosen (50%)	62	44.0
C chosen (1/2) with wrong answer(s)	1	0.7
H chosen (50%) with wrong answer(s)	2	3.5
E chosen (25%)	10	7.1
Average score = 72.4		

This is the easiest question in the probability section and the students did well in this question. 70.2% of students know that the couple has 50% probability to have a baby boy. However, 28.4% of students missed the answer 1/2. Perhaps, the concept of percentage is easier than the concept of a fraction, so students pick up the percentage answer fast, and somehow ignore the fraction answer.

However, the difficulty might be in how students see the answer C. Do they read it as one half and then are unable to translate that into a probability idea of 50%? Can they read it as one in two which is nearer the probability thinking? It is quite possible that the difficulties in grasping ideas in probability are that there are multiple ways of expressing probability and that students do not easily move from one to another. Thus, they ‘see’ 1/2 as meaning one half and cannot relate that to one chance out of two or a 50% probability. Probability is expressed as percentages and as ratios of one and the two systems are confusing for the novice learner.

Table 6-12: The responses of students to part 3, question 2 of the pre-knowledge test of genetics.

3-2: If a couple decided to have two babies: How many possibilities of babies gender can happen?	N=141	
Response (Correct = B)	**No.**	**%**
Correct answer chosen (3)	56	39.7
B chosen (3) with wrong answer(s)	1	0.7
G chosen (2)	38	27.0
C chosen (1/2)	15	10.6
E chosen (25%)	14	9.9
H chosen (50%)	13	9.2
Average score = 40.4		

The answer is 3: two boys, two girls, and one boy and one girl. The most common wrong answer appears to be G (2). Students might only think two boys and two girls and slip up on the answer one boy and one girl. Clearly, two kinds of gender are misleading the students thinking.

Table 6-13: The responses of students to part 3, question 3 of the pre-knowledge test of genetics.

3-3: What is the probability that they both are boys?	N=141	
Response (Correct = E and F)	**No.**	**%**
Both correct answers chosen (25% and 1/4)	15	10.6
E chosen only (25%)	32	22.7
F chosen only (1/4)	23	16.3
E chosen (25%) with wrong answer(s)	3	2.1
F chosen (1/4) with wrong answer(s)	2	1.4
H chosen (50%)	31	22.0
C chosen (1/2)	24	17.0
I chosen (3/4)	13	9.2
Average score = 41.4		

There are some findings from Table 6-14; while around 50% of students think there is a one in four chance to have two boys, an interesting feature is that around 40% of students think the chance is a half. Obviously, this demonstrates their confusion about or the lack of understanding of the principle of probability laws.

Table 6-14: The responses of students to part 3, question 4 of the pre-knowledge test of genetics.

3-4: What is the probability that they have one boy and one girl?	N=141	
Response (Correct = C and H)	**No.**	**%**
Both correct answers chosen (1/2 and 50%)	13	9.2
C chosen only (1/2)	27	19.1
H chosen only (50%)	29	20.6
C chosen (1/2) with wrong answer(s)	2	1.4
H chosen (50%) with wrong answer(s)	2	1.4
F chosen (1/4)	29	20.6
E chosen (25%)	24	17.0
I chosen (3/4)	12	8.5
Average score = 41.5		

This result is response to question 3-3. Students do not understand the combination of one boy and one girl could be either a boy first then a girl or a girl first then a boy.

Table 6-15: The responses of students to part 3, question 6 of the pre-knowledge test of genetics.

3-5: If the first child is a boy, what is the probability that their second child is a boy?	N=141	
Response (Correct = C and H)	**No.**	**%**
Both correct answers chosen (1/2 and 50%)	12	8.5
C chosen only (1/2)	23	16.3
H chosen only (50%)	24	17.0
C chosen (1/2) with wrong answer(s)	1	0.7
H chosen (50%) with wrong answer(s)	3	2.1
E chosen (25%)	31	22.0
F chosen (1/4)	30	21.3
I chosen (3/4)	17	12.1
Average score = 35.4		

The probability of the gender of second child is independent of the first one. However, many students counted the first child as a factor thus they chose 25% or 1/4. The result showed again that many of the students do have misunderstandings and the unclear concept about the probability.

6.6 Conclusions

This chapter reports the findings of an investigation which probed some aspects of the previous knowledge and preconceptions of students before they started their studies in genetics. After analysis of the syllabus, three major topics (the concept of hereditary information in the cell, understanding of mitosis and meiosis, and the principle of probability) were considered the foundational concepts for reaching students' acquisition of meaningful understanding of inheritance.

A thorough analysis of the responses revealed that there had appeared to be widespread confusion and uncertainty, much of which was related to the students having developed ideas which were inconsistent with those accepted by the wider scientific community. Students are showing a lack of basic and clear knowledge about the cell structures involved, such as gene, DNA, and chromosome and often mix up their functions and locations in the cell. It seems that students are quite vague about these terms.

About students' understanding of the processes, purposes, and products of cell divisions, as expected, the findings confirm that most students seemed to be unaware of the nature of the difference between mitosis and meiosis. Even though the chapter on reproduction had been taught shortly before the students did this test, the average scores of this part are still relatively low, especially in the relationships between the behaviour of chromosomes at cell divisions. This supports the general picture obtained from the interview data from Wood-Robinson *et al*. (1997).

Moreover, students seemed to be able to carry out routine calculations relating to probability with reasonable competence. However, applying these probabilistic ideas to the field of genetics was of considerably greater difficulty. They tended to fail when the question was more complicated, suggesting that the ideas were not fully understood. This is consistent with the findings of Kinnear (1983) and Lewis and Wood-Robinson (2000) who showed that, while understanding of probability was shown to be generally good, the ability to apply it within the context of inheritance is variable. In addition, another worry is when students picked the right answer, it means whether they do understand the meaning or they just mechanically calculate the result. However, it is another issue that should be checked out and studied further.

Overall, students have their own ideas about some aspects of inheritance before they receive tuition on the genetics. These ideas, which often do not conform to those that are to be taught, may be a consequence of previous instruction on other biological topics (such as cell structures, cell divisions) or informal ‘common sense’ knowledge from everyday experience and language. The knowledge of these confusions can be used to anticipate some of the difficulties students might have in understanding genetics. From a constructivist point of view, these ideas may serve as a basis or foundation upon which new learning and knowledge may be built, and thus can serve to help teachers plan more effectively and to select the best sequence of content for introducing learners to genetics. Obviously, these ideas should be taken into account by teachers when planning and teaching; if they are not, and if they are erroneous, they could interfere with the acquisition of scientifically acceptable knowledge about genetics.

Chapter Seven

Results and Discussions II

7.1 Introduction

The research study seeks to explore the learning problems in genetics. The first stage in this study had looked into some aspects of the previous knowledge and preconceptions of students hold before they have their first formal genetics course. The focus of this chapter is an exploration of psychology aspects of the learning of genetics.

Research carried out over the years revealed that some psychological factors, such as the size of the working memory space and the degree of field dependence do influence student's performance in learning and in assessments of various subjects, especially in sciences (e.g. Danili, 2001; Bahar and Hansell, 2000; Al-Naeme, 1991; El-Banna, 1987; Berger, 1977). This chapter will describe the second stage of the research which investigated into these psychological factors which may affect the outcomes of adolescent students' learning in genetics.

The instruments used in this part of the experiment are described along with detail about the sample of learners chosen. Then, the results, analyses and discussions of the findings from the study instruments are presented.

7.2 The study sample

The present research was conducted in Taiwan with the same students of the first year of public junior high school (aged 13 approximately) as used in the pre-knowledge experiment (Chapter six). It was decided to work with this group simply because this is the only stage when all students in Taiwan are taught genetics. As mentioned in the former chapter, after junior high school education, genetics only features in the curriculum for the students who are taking biology/genetics as a separate subject.

The experimental framework is shown in the Figure 7-1. The total population of students participating in the measurement of psychological factors and prior knowledge and understanding in genetics (pre-instruction and post-instruction) consisted of 141 students from five classes; boys are 78 and girls are 63. The data from school formal examinations, which include overall biology scores and genetics scores, was used to match up these students samples.

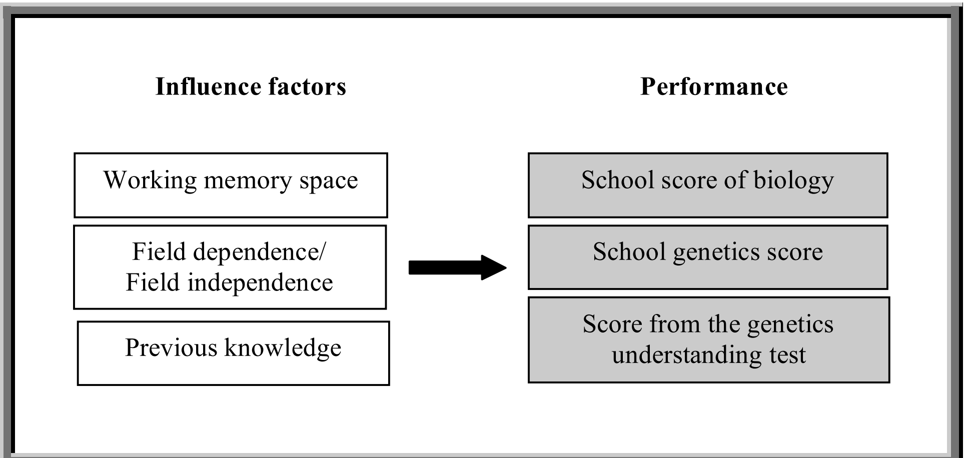


Figure 7-1: The experimental framework of this part of study.

7.3 The study instruments

The following assessment tasks were used:

1. The measure of the working memory space capacity of the learners: the figural intersection test was used (see section 5.2 in Chapter five and Appendix A);

2. The measure of field dependence/field independence of the learners: the group embedded figures test was used (see section 5.3 in Chapter five and Appendix B);

3. The measure of prior knowledge test of the learners in genetics: the structural communication grids approach was used (see Chapter six); and

4. The learners' performance: this includes (see overleaf)

- The overall scores of biology: it consisted of all biology scores from the school's formal examinations in an academic year. Biology course in junior high school in Taiwan is one-year course and it has three formal examinations in one semester, so total are six examinations a year. The examination in Taiwan is usually scored from 0 to 100.
- The genetics scores: it is from one of the school's formal examinations which tested students' knowledge about reproduction and inheritance. The examination was scored from 0 to 100.
- The genetics understanding scores: a test was designed to probe students' understanding in genetics (Figure 7-2).

The research design of the understanding test of genetics is based on the former research, including Lewis and Kattmann (2004), Marbach-Ad (2001), and Lewis *et al.* (2000c), and discussion with the reputable researchers in science education and experienced biology teachers in Taiwan. For testing it, a sample of 17 students (aged 13 to 16) from Glasgow Chinese School Stow College was selected. Students' responses were examined and a few of them were interviewed in order to clarify their ideas.

The understanding test of genetics aimed to probe conceptual understanding about genetics rather than factual recall and used a combination of fixed and free response formats, for example, the logical sequencing, open questions, comparing questions, and structural communication grids etc. The test is divided into four sets of questions (Figure 7-2):

1. Genetics terms: probed students' general understanding of the terms gene, DNA, chromosome, nucleus, cell, and organism, including ideas relating to location, function, and relationship;

2. Genetic information: probed students' understanding of the situations of genetic information between cells and cells from the different parts of the body within the individual and the situations of genetic information of the cells from the same part of the body between two different individuals;

3. Application of Punnett square: probed students' understanding of the probability of inheritance by using the Punnett square and its principle and concept; and

4. Inheritance of sex chromosomes: probed students' understanding of the processes by which sex chromosomes are transferred to the next generation.

The understanding test of genetics is in Chinese language and the English version is shown in Figure 7-2. It was completed in May 2004 after students were taught the section on genetics (there are nine hours of teaching within three weeks involved). The total test time is around 25-30 minutes. The entire answers of the test are given in Appendix D.

Understanding Test of Genetics

Name: ____________________ Sex: ☐ Boy ☐ Girl

This is a test of your understanding about genetics.
There are four parts. Please follow the instructions to answer the questions.

The results of this test will not affect your schoolwork in any way.
Thank you very much!

Centre for Science Education, University of Glasgow, Scotland.

Part 1: Comparing

(1) The six biological items in the list below are all parts of living system:

Cell	Chromosome	Gene	DNA	Organism	Nucleus

Now write the items in order of size in the boxes. Start with the smallest.

Smallest							Largest

(2) Please explain the relationships between two genetics terms below.
- Gene/DNA: ____________________
- DNA/Chromosome: ____________________
- Gene/Organism: ____________________

Figure 7-2: Understanding test of genetics.

Continued

Part 2: Same or Different

The following tables are "comparing questions" between cells and cells within the individual, and between human and human. If the answer is same, please write "**S**"; if it is different, write "**D**".

Here is an example:

	Apple and Strawberry	Grape and Orange	Kiwi and Banana
The colour	**S**	**D**	**D**
The shape	**D**	**S**	**D**

(1) There are several kinds of cells, which complete all structures and functions of a human being. According to your genetics knowledge, please compare the situations of genetic information between the following cells from the different parts of your body.

	Muscle cell and Muscle cell (in different parts of the body)	Muscle cell and Nerve cell	Muscle cell and Germ cell (Sperm or egg)	Germ cell and Germ Cell (Sperm or egg)
The number of chromosomes				
The size of chromosomes				
The number of genes				
The type of genes				

(2) In this world, some people look like you, but others don't. Please compare the following situations of the somatic cells between you (You are Taiwanese) and other people.

In the somatic cells	You and Scottish	You and Your father	You and Your mother	You and Your brother or sister	You and Your classmate (Taiwanese)
The number of chromosomes					
The size of chromosomes					
The number of genes					
The type of genes					

Part 3: You are a geneticist!

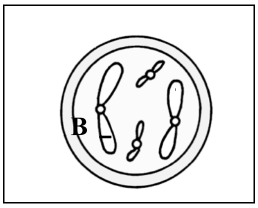
We know there are two kinds of eyelids in the Chinese population. One is single-edged eyelid, and the other is double-fold eyelid. The double eyelid versus the single eyelid is dominant that we use "B" to represent its gene.

If a man and a woman are married and both of their eyelids are double-fold (the genotype is Bb).

Figure 7-2: Understanding test of genetics.

Continued

(1) In the following picture, one of the genes loci of the man's eyelids is marked (B). Please mark the other gene locus (b). (Here only shows two pairs of chromosomes of a human being.)



(2) Use Punnett square method to predict the possibility of their children's traits.

- Please explain the meaning of 1/2B that you write in the Punnett square.
  1/2 means ____
  B means ____

(3) Please answer the following questions in accordance with the results from Punnett square:

- Is it possible that the couple has a child with single-edged eyelids? __________ (yes or no). The probability is__________.
- Is it possible that the couple has two children with single-edged eyelids? _________ (yes or no). The probability is__________.
- Is it possible that all children's eyelids of the couple are double-fold and no single-edged? __________ (yes or no). Why? ____

Part 4: Give Mary a hand

After genetics lecture, Mary has some questions about inheritance of human sex chromosomes which really confused her. Could you help her to solve these?

There are some hints (nine boxes) to help you answering questions, which are labelled English letters from A to I on the upper left.
Please select the box(es) to answer the following questions - use English letters to show your answers and boxes may be used as many times as you wish.

A Father	**B** Mother	**C** X
D Germ cells	**E** Somatic cells	**F** Y
G 0	**H** 50%	**I** 100%

Figure 7-2: Understanding test of genetics.

Continued

(1) Which cells do contain sex chromosomes? - ____________

(2) From whose X chromosome does Mary inherit? - ____________

(3) If Mary has a brother, whose X chromosome does he inherit? - - - - - - - - - - - - ____________

(4) There are two daughters in Mary's family. If Mary's mother wants a son, what is the possibility she can get that? - ____________

(5) If Mary's mother had the double-fold eyelids surgery, what is the possibility that the next son get this trait from her? (The trait of double-fold eyelids is dominant) - ____________

(6) The following figure indicates human chromosomes' arrangement to determine the gender of next generation and keep the numbers of chromosomes of next generation constant. Please complete these question marks in the figure using the boxes above.

❶__________
❷__________
❸__________
❹__________
❺__________

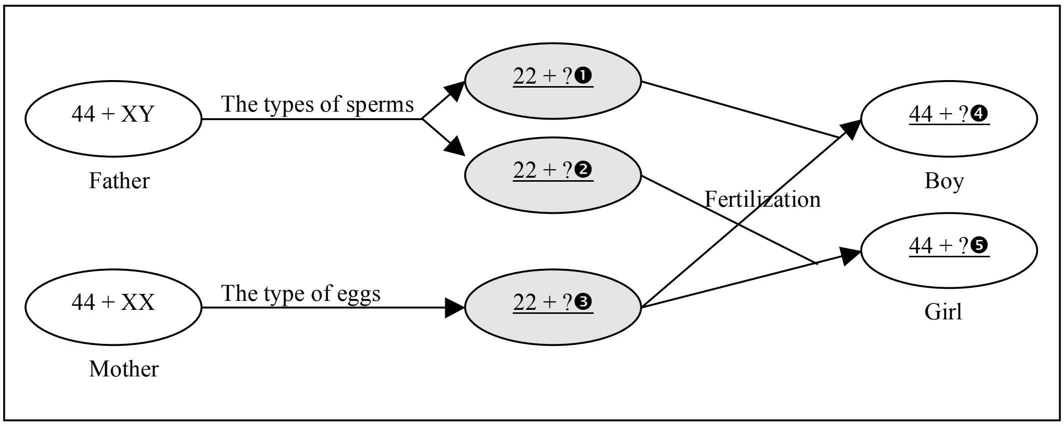


Figure 7-2: Understanding test of genetics.

7.4 Methods of analysis

The scoring scheme for the figural intersection test was based on the work done by previous researchers (e.g. Chen, 2004; Bahar, 1999; Su, 1991; Ziane, 1990). The size of a student's working memory capacity was determined by the highest number of shapes in the test that the student was able to answer correctly. The test has 36 questions in total. The number of shapes in each question varies from two to nine. There are several questions with the same number of shapes: usually around five. If a student can give most of the questions the correct answers up to five overlapping shapes, he/she is considered to have a working memory space equal to five.

After marking all responses, students in this study were classified into three categories namely: low, middle, and high working memory capacity. In order to create the categories with roughly the same number of students in each category (around 33% in each category), students who scored more than one half of a standard deviation above the mean score were classified as having high working memory capacity and those who scored less than a half standard deviation below the mean score were classified as having low working memory capacity. Students whose scores were between the two categories were classified as having middle working memory capacity.

For the FD/FI test (group embedded figures test), the scoring scheme was to give one point for finding a correct simple shape embedded in a complex figure and then sum up the scores. The instrument was scored from 0 to 20 (because of 20 figures in total) with higher scores indicating a higher degree of field independence and vice versa for field dependence. The intermediate between field independence and field dependence is classified as field intermediate.

The classification formula which is similar to the one used to determine the working memory capacity categories has been used by many researchers (e.g. Ghani, 2004; Bahar, 1999; Al-Naeme, 1991). Students who scored more than a half standard deviation above the mean score are classified as field independent, while students who scored under a half standard deviation below the mean score are classified as field dependent and between a score of -0.5 S.D. and +0.5 S.D. are considered as field intermediate.

The scores of the genetics understanding test were marked in different ways due to the character of the various questions. Students were given one point for giving a correct answer to a question. For the open questions, it was allowed to give half point if the student's answer was not exactly right. For the sequence question, scores were allocated for each pair of items if they are in proper order and no matter where they were in the sequence. Marks were added up after checking each pair in turn.

For structural communication grids in part four of the test, the method of scoring is the same as the pre-knowledge test of genetics which was described in section four of Chapter five and Chapter six. After marking, scores were obtained by summing. Four parts of the test were scored separately and every part of the scores was adjusted to 100.

Moreover, in order to look at the relationships between some of psychological factors (the working memory capacity and the FD/FI) and student's performance in learning genetics, the statistics analysis correlation was employed.

7.5 Results and discussions

In this section, the relationships within/between the psychological factors, which include the working memory capacity and the FD/FI, and students' performances and achievement in genetics are discussed.

7.5.1 Results of figural intersection test and group embedded figures test

Table 7-1 shows students' results of the figural intersection test for measuring the working memory capacity and the group embedded figures test for measuring the FD/FI.

Table 7-1: The descriptive statistics data of the figural intersection test and the group embedded figures test.

N=141	**The test target**	**Mean**	**S.D.**
Figural intersection test	Working memory capacity	5.2	1.4
Group embedded figures test	Field dependence/independence	8.4	4.4

This is known that the average working memory capacity for adults (from aged 16) is seven and most adults will have working memory spaces between five and nine, and that the working memory capacity grows by about one unit for every two years of age (Cowan, 2001; Miller, 1956). At the age of the Taiwanese students in the first year of junior high school (aged around 13), their average working memory space will be perhaps around one to two units less than the adults' average, of course with a spread. The results in Table 7-1 show that the average working memory space of Taiwanese students in this stage is 5.2 and the standard deviation is 1.4. This is approximately what might be expected.

It is similar to results obtained by other researchers who chose the samples from the same age group but from different countries (different race and culture background) (e.g. Jung, 2005; Al-Enezi, 2004; Cowan, 2001). However, there is no evidence that there are differences caused by culture, race, or gender.

In order to explore any relationship between psychological factors as well as between psychological factors (section 7.5.1) and students genetics preformance (section 7.5.3), the statistic correlation and the classfication were applied. Firstly, from the results of the figural intersection test, the sample of 141 junior high school students was devided into three groups representing their levels of the working memory capacity: low, middle, and high working memory capacities. Using the formula mentioned in the section four of this chapter, students with a score of six or more were classified as having high working memory capacity. Students with a score of five were classified as having middle working memory capacity. The rest with four or less than four were classified as having low working memory capacity. The results of classfication are shown in Table 7-2.

Table 7-2: The classification of students into three working memory capacity groups (N=141).

Group	Number of students
High working memory capacity (≥6)	46 (32.6%)
Middle working memory capacity (=5)	54 (38.3%)
Low working memory capacity (≤4)	41 (29.1%)

Though the figural intersection test is known to be fairly accurate (Johnstone and Elbanna, 1989), the results must be treated with caution: only one test cannot guarantee to give a 100% accurate measurement. For more assured measurement of the working memory space, the ideal would be to use two tests, one visual and one symbolic. Values would be assigned after comparison between the two tests. However, access time with the students did not allow the use of two tests. Of even greater importance, it is important to note that the scores were not being used in this study as absolute values. In this research, they are treated in a relative sense.

From the distribution of total scores of the FD/FI test (Table 7-1), it was found the mean of the score was 8.4 and the standard deviation was 4.4. The sample of 141 students of the Taiwanese junior high school were devided into three distinct categories representing their levels of the FD/FI. Those who scored six or less were considered to be field dependent learners while those who scored 11 or more were labelled to be field independenct learners. Others who were not in these two categories were labelled as being field intermediate learners. The students classfication into three categories is shown in Table 7-3.

Table 7-3: The classification of students into the FD/FI categories (N=141).

Group	Number of students
Field dependence (≤6)	54 (38.3%)
Field intermediate (7-10)	38 (30.0%)
Field independence (≥11)	49 (34.8%)

The size of the working memory capacity and the FD/FI cognitive styles are two different independent developmental characteristics. Nonetheless, many studies found there was a significant positive correlation between them (e.g. Hindal, 2007; Al-Enezi, 2004; Bahar, 1999; Ziane, 1990; Al-Naeme, 1988), but some of the studies did not show this relationship (e.g. Ghani, 2004; Danili, 2001).

The relationship between the two measurements has been explained by Johnstone (1997). He argued that, while the working memory capacity is a measure of the size of that part of the brain, extent of field dependency is one aspect of the efficiency by which a person uses their working memory. By selecting information more carefully, the working memory can function better, being less cluttered by extra information. This might explain the correlations often observed.

In this study, the Pearson correlation between the working memory capacity scores and the extent of the FD/FI scores was found to be 0.48 ($p<0.001$, 2-tailed). This is one of the highest values obtained. It means that field independent students tend to have higher scores in the test for measuring working memory space than field dependent students. It could be explained that field dependent students, because they are less able to select efficiently than field independent students, tend to achieve lower scores in a working memory test.

The distribution of the FD/FI students over students with low working memory capacity/high working memory capacity is given in Table 7-4 to make obvious the relationship between the FD/FI and the working memory capacity. From Table 7-4, the majority of field dependent students have low working memory capacity and field independent students tend to have high working memory capacity.

Table 7-4: The distribution of students with field dependence/field independence over low working memory capacity/high working memory capacity.

N=141	**Low working memory** (N=41)	**Middle working memory** (N=54)	**High working memory** (N=46)
Field dependence (N=54)	30	18	6
Field intermediate (N=38)	8	19	11
Field independence (N=49)	3	17	29

7.5.2 Students' performances in genetics examinations

Table 7-5 shows students' performances in genetics examinations (genetics scores and biology scores from school formal examinations and the understanding test of genetics from this study). The data for the pre-knowledge test which was performed before the genetics class started is also shown.

Table 7-5: The descriptive statistics data of students' performances in genetics examinations.

N=141	**Minimum**	**Maximum**	**Mean**	**S.D.**
Pre-knowledge test	10	78	38.9	15.0
Genetics scores	24	94	62.5	19.5
Overall scores of biology	24	94	68.4	16.3
Genetics understanding test	16	93	58.2	18.1

As the students' scores in the genetics understanding test and in school genetics examination were plotted against each other, a significant correlation emerged ($r=0.80$, $p<0.001$, 2-tailed). It was also shown on the overall scores of biology ($r=0.80$, $p<0.001$, 2-tailed). Thus it could be concluded that these school examinations in Taiwan involve in probing conceptual understanding and dispel prejudice against only testing in rote learning.

The scores of students in the pre-knowledge test and the three performance tests were set out against each other. A significant correlation emerged (Table 7-6).

Table 7-6: The correlations between the pre-knowledge test and three performance tests (N=141).

Performance	Correlation coefficient	p
Genetics scores	0.68	p<0.001
Overall scores of biology	0.67	p<0.001
Genetics understanding test	0.64	p<0.001

What was being tested in the pre-knowledge test was the underlying ideas which were thought to be important in making sense of the genetics course. Thus, the more correct underlying knowledge the students had, the better performances they had. On the other hand, students' prior knowledge which could be either misconceptions or lack of knowledge did influence on genetics learning.

7.5.3 The relationships between psychological factors and students' performances in genetics examinations

To find out if there is any correlation between psychological factors (working memory capacity and FD/FI) and students' performances in genetics examinations (the genetics scores, the overall scores of biology, and the understanding test of genetics), a comparison between every category of students' working memory capacities and their mean scores in each test, as well as between every category of the FD/FI students and their mean scores in each test were carried out. The results are shown in Table 7-7.

Table 7-7: The working memory capacity of students and the FD/FI students related to mean scores in the genetics tests.

N=141	Genetics scores	Overall scores of biology	Scores of the understanding test
High working memory	72.4	77.3	65.6
Middle working memory	67.5	71.8	59.8
Low working memory	52.2	59.9	51.6
Field dependent	51.8	60.1	50.3
Field intermediate	62.5	68.3	57.5
Field independent	74.3	77.6	67.5

According to Table 7-7, students with high working memory space performed better in all genetics tests than students with intermediate working memory space, and students with intermediate working memory space performed better than students with low working memory space counterparts. Also, it shows very clearly that field independent students tended to have better scores in all genetics examinations than field intermediate students and, respectively, field intermediate students tended to have better scores in all genetics examinations than field dependent students. Furthermore, the results from the working memory capacity measurement and the field dependence measurements were each correlated with the scores in the various genetics tests and the results are shown in Table 7-8.

Table 7-8: The correlation coefficient values between psychological factors and students' performances in genetics tests.

N=141	Genetics scores	Overall scores of biology	Scores of the understanding test
Working memory capacity	0.61	0.62	0.45
Field dependence/field independence	0.48	0.46	0.38

Correlation is significant at 0.001 level (2-tailed).

All of the correlation coefficient values obtained were very high ($p<0.001$). Thus, it can be concluded that high working memory students showed the better performances and had higher marks in the genetics tests than low working memory students. Field independence tended to achieve better scores in the genetics tests than field dependence.

These results support the previous conclusions and they are consistent with the findings from other research even though the study disciplines and/or sample population are different (e.g. Johnstone *et al*., 1993; Geary and Widaman, 1992; Opdenacker *et al*., 1990; Johnstone and El-Banna, 1986).

Working memory will only show correlation if the teaching or the assessment makes a demand on the working memory, so that those with higher working memory capacity have an advantage. In an interesting experiment, Pamela Reid (2002) showed that it was possible to reduce the correlation to zero if the test material was carefully constructed. She showed that this was nothing to do with the difficulty of the test. Her test was difficult but the results, with a large sample, did not correlate significantly (in fact, the correlation was close to zero) with the working memory capacity.

As mentioned in Chapter three, the structure of the genetics knowledge is complex and students have to use this complex knowledge in solving complex genetics tasks. In order to grasp the overall picture of genetics, several levels (macro/micro/symbolic) of organisation must be integrated. Therefore, it could be interpreted that students with high working memory space who are field independent may have an advantage with the complex nature of genetics, because they have higher capacities to receive, to hold, and to manipulate the complex information. In addition, the field independent persons whose analytical and restructuring abilities are more capable than the field dependent ones to organise the different levels of genetics knowledge and to comprehend the knowledge from different subjects.

Therefore, it could be inferred that field independent students of high working memory capacity may learn more efficient so achieve better marks in the tests than those who are field dependent students with low working memory capacity. The results in Table 7-9 show again this tendency.

Table 7-9: Field independence with high working memory capacity and field dependence with low working memory capacity related to mean scores in three genetics tests.

	Genetics scores	Overall scores of biology	Scores of the understanding test
Field independence with high working memory capacity (N=29)	76.0	79.9	68.0
Field dependence with low working memory capacity (N=30)	45.0	53.2	45.8

In fact, the differences in performance between those with high working memory capacity with field independence and those with low working memory capacity with field dependence are extremely large: from about 22% to 31%. This indicates that being field independent with a high working memory has a huge advantage in the tests being used in Taiwan or/and in genetics studying.

Much other research found that a relationship exists between the working memory space capacity, the FD/FI, and students' performance (e.g. Ghani, 2004; Christou, 2001; Danili, 2001; Bahar, 1996). Students with low working memory space but who are field independent have a similar performance when compared with those who have high working memory space but who are field dependent. Due to the quantity of the sample in this study is not enough to represent the real population after classified into three categories of the working memory capacity and the FD/FI respectively (Table 7-4), the data are not presented here.

Johnstone *et al*. (1993) suggested that students with low working memory space but who are field independent have the ability to distinguish the essential information from irrelevant and they can use their whole working memory space while students with high working memory space but who are field dependent have part of their working memory space occupied by irrelevant information. Thus both of them have almost the same working space capacity and therefore almost similar results in the examinations.

7.6 Conclusions

Research carried out over the years revealed that the size of the working memory space and the degree of field dependence have influenced student's performance in different subjects of learning and assessments and different age population of students (e.g. Ghani, 2004; Danili, 2001; Bahar, 2000; Al-Naeme, 1991). For genetics from biology and junior high school students, this was a new area to be explored.

The study results showed that the average working memory capacity of aged 13 students is around five, which was consistent with the findings of other research studies. Moreover, there was a significant correlation between the working memory capacity and FD/FI. Field independent students tended to have high working memory capacity and field dependent students tended to have low working memory capacity.

Relationships existed between students' outcomes in learning genetics and their pre-knowledge/preconceptions, as well as the working memory space capacity and the FD/FI. The correct basic knowledge helped students in understanding genetics and the misconceptions affected their learning. Otherwise, high working memory space capacity students performed better in the genetics examinations than low working memory space capacity students and field independent students tended to achieve better scores in the genetics examinations than field dependent students.

Moreover, students who belonged to high working memory capacity and field independent category performed the best in all the genetics examinations while the worst performers were the students in low working memory capacity and field dependence category. Therefore, when designing teaching materials, these psychological factors should be taken into consideration.

According to the information processing model, it is known that the working memory space capacity is limited and can handle only a limited amount of information in a given time. When information overload occurs, learning will be minimal. Genetics certainly has the potential to generate such an information overload. Thus, when new teaching materials are introduced to the learners, the teacher should control the amount of useful information (the signal) which the learner has to process and can also limit the extraneous distracting information (the noise) in a learning situation (information load at one time at a reasonable minimum).

Chapter Eight

Results and Discussions III

8.1 Introduction

In the first and second stages of the research, factors causing the difficulties and problems of learning genetics were identified. This chapter will describe the third experiment of this study which looked to develop a series of instructional approaches to improve students' conceptual understanding and to be aware of more social implications of genetics as well as to encourage more positive attitudes.

The main experiment focused on junior high school students who were separated into the experimental group and the control group. The experimental group was taught using new teaching approaches and the control group was taught by normal teaching ways. Very often, the traditional strategies for teaching biology/genetics rely on the teacher explanation and textbooks. After instruction, both groups were evaluated in terms of performance and attitude development in order to find out whether the teaching approaches were helping students in their learning and understanding in genetics as well as whether attitudes toward genetics and its social implications were developing.

In addition, the study also attempted to explore attitude development related to age. Thus, attitudes for three age groups (junior high school student, senior high school students, and undergraduates) were measured.

The approaches used are described along with detail about the sample of students chosen. The results and analyses as well as the discussion of the study's findings are then presented.

8.2 The study sample

The new teaching material was applied to 180 first year students of junior high school in Taiwan as the experimental group (aged 13 approximately). The control group is 181 students from the same junior high school and they were taught by the traditional way. The performance of the 361 students from both experimental and control group were evaluated by means of the school formal examination and a word association test developed for the purpose.

The attitudes questionnaire was applied to these 361 junior high school students as well as 188 senior high school students and 209 undergraduates. All three groups sampled for a cross-section of the population.

All of this is set out in Figure 8-1. These experiments and tests were done in spring 2005 in Taiwan.

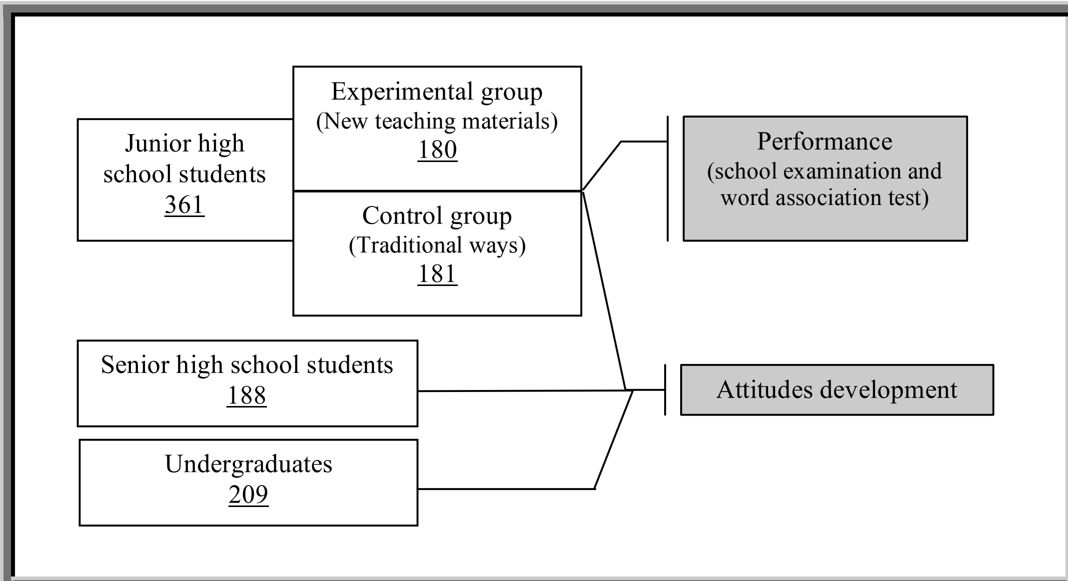


Figure 8-1: The sample size of each test.

8.3 The study instruments

From previous research, findings showed that genetics is one of the most difficult topics in the biology curricula to teach and to learn and the understanding of genetics ideas of the majority of students is thought to be very poor (Gott and Johnstone, 1999; Johnstone, 1991). Indeed, there appears to be widespread uncertainty and confusion among students of various levels and among the population in general. A thorough analysis of the results has showed that traditional teaching strategies seem to have effects on certain ways of students' meaningful understanding of inheritance (Pashley, 1994a; Stewart, 1982a).

It is known that understanding genetics is difficult and requires a certain level of abstract thought. From a Piagetian perspective, the first year of junior high school students (aged around 13) are entering the level of formal operational thinking and should be able to cope adequately with these ideas. However, not all this population will have reached this stage (Shayer and Adey, 1981). Some science education researchers have suggested that there is a need to develop strategies and didactic sequences that facilitate cognitive development toward formal thinking (Tolman, 1982) and the revision of basic concepts necessary to understand genetics through the modification of curriculum materials in order to create a more familiar context for the inheritance process (Hackling and Treagust, 1984).

The results from this study and others (such as Wood-Robinson, 1994; Kargbo *et al*., 1980) have shown that young people use their own intuitive ideas to explain some aspects of inheritance before they receive tuition. These ideas sometimes do not conform to those that they will be taught. From a constructivist perspective, previous knowledge will serve as a basis or foundation upon which new learning and knowledge build. Obviously, these should be taken into account by teachers when planning and teaching; if they are not, and if they are erroneous, they could interfere with the acquisition of genetics knowledge. Researchers have suggested quite a variety of organisation approaches for biology textbooks to encourage correct conceptual development as well as suggesting the type and extent of practical support in an effort to encourage students to give up their alternative conceptions on genetics (Kindfield, 1994; 1991; Brown, 1990; Cho *et al*., 1985, Longden, 1982; Johnstone and Mahmoud, 1981).

From the information processing approach point of view, the learning difficulties in genetics might be interpreted and explained in terms of the way the learner processes information with the limitation of the working memory space being critical. Firstly, genetics is rich in terminology, which takes up valuable working memory space when learning (Johnstone, 1991). Secondly, inheritance has to do with many levels of biological organisation and an adequate understanding of genetics require 'to-and-fro' thinking between molecular, cellular, organism, and population level (Knippels *et al*, 2005). Using several levels simultaneously is likely to bring about an information overload (Johnstone, 1991). Finally, it is possible to overload memory simply by the conceptual nature of genetics because the learner has to hold several ideas at the same time in an attempt to make sense of what is being taught (Ramorogo and Wood-Robinson, 1995). For example, the student learns the new and abstract words, and at the same time is learning new concepts in that vocabulary. Therefore, in order to facilitate teaching and learning processes, it is important for teachers to (Chen, 2003; Bahar, 1999; Johnstone and Wham, 1982; Case, 1974):

- Organise the teaching materials carefully;
- Keep the information at a minimum;
- Keep the learners informed clearly;
- Allow time for working memory to cope;
- Even use learners' language; and
- Allow practice and feedback.

On the other hand, while scientists have explored the secrets of genome maps and applied the knowledge in medicine and agriculture, releasing findings to the media, and applications in the real world, there is considerable doubt whether the public and students have an adequate understanding of genetics so as to understand the real meaning of this work or have correct attitudes to express their thoughts. We need to prepare our students for citizenship. Young people need to be informed, not only about knowing and understanding the practical applications of genetics, but also they need to appreciate the social and ethical implications, so that they can make wise personal choices and contribute to public debate in the future.

Thus, in school education, the goal of learning genetics is not only to provide a supply of geneticists, biotechnologists, and trades personnel for society, but also to raise and extend the general level of knowledge, understanding and awareness of genetics and its relatedness in the population as a whole. Moreover, it is important to promote a positive attitude towards engaging with genetics because attitudes established toward genetics will determine a person how he/she will use his/her knowledge, whether he/she will have a desire to study the subject further, and even in taking it for a career.

In a review, Reid (1999) concluded that the key to positive attitudes arising from many studies was that the material being learned was perceived by the learner as related to his/her lifestyle, aspirations, and interests. When designing a new curriculum, it is suggested that teaching science embedded in technological and social contexts familiar to students: a STS (Science-Technology-Society) approach, in order to help students make sense out of their life today and for the future as well as develop students' attitudes towards science and scientific literacy (Solomon, 1993; Fensham, 1992; 1988; Aikenhead, 1986; Bybee, 1985).

As mentioned in Chapter two, the STS instruction has tended to encourage participation by students, enhance student motivation and attitude development, and therefore achievement (Byrne and Johnstone, 1988). The teaching methods which have been suggested include cooperative learning, peer support, issue-based techniques, and connected knowledge by using simulations, small group work, group discussions, debates, problem solving, decision making, role playing, divergent thinking, or using the media and other community resources (Solomon, 1993; 1989; Aikenhead, 1988; Byrne and Johnstone, 1988).

Based on the evidence from previous research and the principles which the researchers suggested, the teaching material in genetics was developed. In order to make the curriculum accessible, some of the teaching factors were considered: order, presentation, sequencing of ideas, contexts, laboratory work, and applications. Very often, the teaching material was designed around applications and life examples, which made sense to the students and perceived as related to them. Great care was taken in the way of the material was organised and presented so that working memory overload was minimised.

8.3.1 The teaching material

The teaching material made up a set of lessons developed for the genetics course of first year of junior high school in Taiwan. The main aim of this material was not only to teach basic knowledge and concepts about genetics but also to encourage the students to apply their ideas to real life situations. In the end, it was hoped that this enabled pupils to be aware of more social implications in genetics and lead them to a greater appreciation of the importance of works in genetics in our society today and in the future. To develop the new teaching material, some limitations had to be taken into account due to the Taiwanese education background:

- It had to cover the material required by Taiwanese curriculum;
- It had to fit the time available in the curriculum;

The lessons were presented under five themes (nine hours of teaching involved). They are basic terminology, theory of heredity, human inheritance, sex determination, and genetics in our lives. It should be pointed out that not all the contents of the units were original. Some ideas were derived from the national biology textbook in Taiwan but much was original. The teaching material was developed by using different approaches, which are outline in Table 8-1, and then considered critically by experienced biology teachers and science education researchers before amendments and refinements were introduced. They were then translated into Mandarin and the translation checked.

Table 8-1: The themes of the new teaching material in genetics and approaches used.

Theme	Lesson	Approaches
Basic terminology	1	Each member has different information and a chairperson. They work through questions to teach other and apply their knowledge to answer questions.
Theory of heredity	2	Historical re-living of some discovery. All have some information of shared problem solving in which all members of a group contribute ideas, or a similar process undertaken by a person to solve a problem by generating the possible solutions.
Human inheritance	2	Through playing games, students understand human traits, human inheritance, also realize the difference between the calculation based theory and the real situation in genetics.
Sex determination	1	Students have opportunities to experience self-studying and self-thinking from problem solving.
Genetics in our lives	2	Students have opportunities to experience self-studying and self-thinking from problem solving and to develop their own attitudes and ideas by multimedia help. By experiencing different views of the same issue, students are encouraged to recognize the many facets of real-life decision taking, to present arguments based on gathered evidence and to listen to the arguments proposed by others.

At the end of the course, the student is expected to:

1. Know the basic terminology related to genetics;
2. Understand the ideas of Mendel;
3. Know how to use a Punnett square to predict the phenotype of offspring;
4. Understand traits and human inheritance;
5. Understand how sex is determined in offspring;
6. Appreciate the nature and role of genetic counselling and genetic engineering; and
7. Understand some of the issues affecting decisions arising from genetics developments (e.g. in the theme of genetics in our lives).

The new teaching instruction was based on the interactive learning approach and STS approach. Students are allowed to interact in groups (sometimes as individuals) with the materials. It provides opportunities for students meaningfully to talk and listen, to write, read, and reflect on the content, ideas, issues, and concerns of an academic subject (Meyers and Jones, 1993). The role of the teacher is sometimes that of manager rather than teacher. Students work together to maximise their own and each other's learning in solving problems, completing tasks and accomplishing common goals (Johnson and Johnson, 1999). Thus, each member of the group is responsible not only for learning what is taught but also for encouraging and supporting other group members to learn and, consequently, creating an atmosphere of achievement and constructing their own knowledge (Ghani, 2004).

By experiencing different views of the same issue, students are encouraged to recognize the many facets of real-life decision taking and to accept that decisions often have to be made on the basis of incomplete information. Students also would have opportunities to assess data presented in several forms, to weigh arguments, to contribute meaningfully to a group discussion, to process self-studying and self-thinking from problem solving, to develop their own attitudes and ideas by multimedia help, to present arguments based on gathered evidence and to listen to the arguments proposed by others. By making the concrete connections between the academic genetics content and the student's everyday world, they should begin to see the importance of genetics ideas in the context of their lives.

Moreover, learning by means of small group activities also increases students' motivation (Nichols and Miller, 1994; Johnson *et al.*, 1991). By working together towards a common goal, group members may develop positive feeling and show greater commitment towards the group and may result in building up considerable camaraderie. This increase in motivation may also lead to improved students' attitudes towards a subject or a course (Felder and Brent, 2001; Giraud, 1997; Nichols and Miller, 1994).

There are some examples of the new teaching material in this study shown in Figure 8-2 and the entire teaching material in English is in Appendix D.

Example 1: Genetics in our lives

Teacher's guide:

(a) Form groups of three pupils and allow them to sit around a desk.
(b) Give each group a set of reading information for further discussion.
(c) Give each student a copy of the sheet entitled, "Cloning Humans: Right or Wrong?"
(d) Allow pupils abut 30 minutes to discuss the questions and write down their agreed answers.
(e) After the group work, ask how many groups favoured human cloning and how many were against it.
(f) Select some groups and ask them for the most powerful reasons they had for or against it.
(g) If time allows, let the students start the exercise, "Homework". This can be completed at home.

Students' material:

Cloning Humans: Right or Wrong?

Please read the papers that your teacher gives you and discuss the following questions.
You will be working in a small group of about three.
Do not try to work on your own!!
After you have discussed each question, you can take it in turns to record your agreed answers.
One of you may be asked to report back on your answers to question 6.

(1) As a group, list as many benefits you can think of which could come from human cloning.
(2) What are the drawbacks which might occur with human cloning?
(3) Do you think cloning can cause ethical (things about right and wrong) problems?
(4) There are three types of parents: gene parents, delivery parents, and care parents.
What kinds of legal problems might arise?

Figure 8-2: Three examples of the genetics teaching material in this study.

Continued

(5) What do you think different religions might have to say about human cloning?
Will it change our beliefs?
(6) As a group, do you think human cloning is a good idea? Give your reasons.

· Homework
Please write a letter to the British Queen (no more than 6 sentences).
Tell her your opinions about human cloning.
Give her some reasons why you recommend or reject that human cloning should be allowed in the UK.

Example 2: Genetics in our lives

Teacher's guide:
(a) Take students to the computer room.
(b) Give each student the sheet entitled, "Genetics in Our Lives"
(c) Allow students to follow the instructions, finding the web sites and completing the answers.

Students' material:

Genetics in our lives

Shrek said:
I'm going to marry Princess Fiona. The king of the kingdom of far far away asks us to do genetic counselling in the hospital.

Princess Fiona said:
I saw some food in the supermarket is labelled GM Food. What's that? And if I eat that, does that make me become normal both day and night.

Prince charming said:
Last week's news indicated that scientists are researching on human cloning! If it is possible, I am going to clone a lot of myself, charming human being.

Donkey said:
I heard genetic engineering and biotechnology are very hot nowadays. They can help agriculture breeding, but also produce medicines. Maybe I'll become a horse one day!

Genetics is more and more important in our lives.
Please surf the following websites and answer questions.

Part 1: Genetic counselling

http://sp1.cto.doh.gov.tw/doctor/book/ch02/book2_2.htm
(1) What is genetic counselling?
(2) Who needs to do this?

http://nature.ckps.tpc.edu.tw/6b/%BF%F2%B6%C7/tree-chap8.htm
(3) What is the carrier of a genetic disease? Answer: __________
(A) A patient with a genetic disease.
(B) A healthy person who has a disease gene. (e.g. genotype is Aa)

Figure 8-2: Three examples of the genetics teaching material in this study.

Continued

http://www.commonhealth.com.tw/New_Life/baby/exam2.htm
Pedigree is very important when we do genetic counselling.
(4) How do doctors know you are not a carrier of genetic disease?

http://content.edu.tw/junior/bio/tc_wc/textbook/ch08/supply8-6-1.htm
(5) How is genetic counselling carried out?
(6) If you needed it, where could receive genetic counselling?
(Choose one where is the nearest your home.)

Example 3: Human inheritance

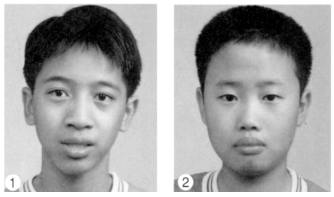
Teacher's guide:
(a) Form groups of four and give each pupil the papers entitled Gamete Combination.
(b) Allow the groups to work through the exercises for the whole lesson.

Students' material:

Human Inheritance (1): Gamete combination

Using Punnett squares allows us to predict the ratios in crosses.
These ratios may differ from those in experimental crosses.

Part 1
The double-fold/single-edged eyelid is a trait inherited from our parents (see the figure). The gene for double-fold eyelid is dominant (R) to that for single-edged eyelid (r).



Double-fold eyelid/Single-edged eyelid

If the genotypes of a couple are Rr x Rr, please use the Punnett squares to predict the ratios in crosses.

The types of offspring genotype ______ ______ ______ ______
The phenotype ratio of offspring ____________________________

Part 2
Use the cards to represent chromosomes. The letter on the card represents a gene:
R is the gene of double-fold eyelid and r is the gene of single-edged eyelid.

R **r** x **R** **r**

Figure 8-2: Three examples of the genetics teaching material in this study.

Continued

(1) You will be working in a group of three:
One member will act as the *father*;
One member will act as the *mother*; and
One member will act as the *child*.
(2) The father will hold the grey cards and the mother the white cards. The grey cards represent the chromosomes in the father's cell, and two white cards represent those in the mother's cell.
(3) One student is to play the father taking two grey cards, and the other student is to play the mother taking two white cards. Place the cards face to yourself.
(4) The third student (playing child) picks one card from the father and one from the mother without looking and then links them together. (So he/she will get one grey card and one white card). This means the gene combination of the first offspring.
(5) Record this result on the following table, and then give the cards back to the parents.
(6) Repeat 3 times.
(7) List the genotypes obtained. Beside each genotypes state the phenotype.
(8) Repeat 16 times.

Number	Genotype	Phenotype	Number	Genotype	Phenotype	Number	Genotype	Phenotype	Number	Genotype	Phenotype	Number	Genotype	Phenotype
1			5			9			13			17		
2			6			10			14			18		
3			7			11			15			19		
4			8			12			16			20		

Answer the following questions.

1. Work out the ratio of phenotype from data 1 to 4.
   The double-fold eyelid's number: ________
   The single-edged eyelid's number: ________
   The double-fold eyelid : the single-edged eyelid = ________

2. Work out the ratio of phenotype from data 1 to 20.
   The double-fold eyelid's number: ________
   The single-edged eyelid's number: ________
   The double-fold eyelid : the single-edged eyelid = ________

3. Collect all data from all classmates and work out the ratio of phenotype.
   The double-fold eyelid's number: ________
   The single-edged eyelid's number: ________
   The double-fold eyelid : the single-edged eyelid = ________

4. Arrange your data:
   Punnett square to show the ratio phenotype is ________
   From data 1 to 4 the ratio of phenotype is ________
   From data 1 to 20 the ratio of phenotype is ________
   From all classmates' data ratio of phenotype is ________

Figure 8-2: Three examples of the genetics teaching material in this study.

Continued

5. If we compare the ratio of dominant and recessive in four children family and twenty children family, which result is close to the theory?

6. After collecting the data from all classmates, how does the ratio of dominant and recessive compare between this experiment and theory?

7. Explain why the actual ratios may differ from the predicted ratios.

Figure 8-2: Three examples of the genetics teaching material in this study.

8.3.2 Word association test (WAT)

As stated in the chapter on methodology (section 5.5 in Chapter five), the word association test can be used as a diagnostic tool to measure understanding of concepts and topics and as an assessment tool to detect concept changes between pre-instruction and post-instruction (Bahar, 1999). In this study, it was for assessing students' genetics cognition in the long-term memory in order to investigate their performance in learning genetics.

At the beginning of WAT, students were given the instruction and two examples. The examiner had to make sure they understood and knew how to answer the test. According to this study of purpose, ten stimulus words were designed for covering both knowledge and social implications in genetics. There were: *Gene, Trait, Dominant, Heredity, Chromosome, Biotechnology, Cloning, GM food, Mendel, and Human genome project*. For each stimulus word, students were required to list ten words, which they considered to be most closely associated with that stimulus word within 40 seconds. The total test time was around seven minutes and controlled by the examiner. The full word association tests are given in Appendix E.

The way to analyse the responses from WAT is to measure the total number of valid responses to each stimulus word. The different responses for a word/concept indicate the individual's links which the person can make to the word/concept (White and Gunstone, 1992). Thus, it could be interpreted that the more meaningful the concept is, the higher the average number of responses is (Bahar, 1999). Indeed, the numbers of responses generated may well be related to extent in which ideas are linked in the long-term memory (Al-Qasmi, 2006). Since stimulus words are ten and the maximum answers of each stimulus word are ten, students' scores range is from 0 to 100, which scale is the same as the score of school examination.

8.3.3 Attitudes measurement

For measuring attitudes (section 5.6 in Chapter five), this study chose the questionnaire to investigate various students' insights into how they think and the way they evaluate situations and experience about genetics. The aim was to see if students had developed more positive attitudes towards their genetics studies and the related issues arising around them. With a questionnaire, it is easy to collect large amounts of information quickly in the limited time.

The entire attitudes questionnaire designed for this research is shown in Figure 8-3. It was divided into three parts and composed of closed and open response questions. Part one was to collect respondents' basic information. Part two was to ask their feelings about genetics course. Part three was to inquire into respondents' attitudes and opinions about genetics applied in our lives.

Dear pupils,

This survey is designed to explore your views about the course you have just completed.
There are not right or wrong answers.
Please give your honest views.
Your responses will not affect your schoolwork in any way.
Please answer ALL questions. Thank you!

Centre for Science Education, University of Glasgow, Scotland.

Part 1: Basic information

School name: __________ Class: __________ No.: __________
Name: ________________ Age: ___________ Gender: □Boy □Girl

Figure 8-3: Attitudes questionnaire in this study.

Continued

Part 2: Students feelings about genetics course.

(1) Please tick [∨] the box which most closely reflects your views:

	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
(a) I enjoyed the genetics course. -	☐	☐	☐	☐	☐
(b) There is too much to learn in the genetics course. - - - - - - - - - -	☐	☐	☐	☐	☐
(c) I can understand genetics in the class. - - - - - - - - - - - - - - - - - -	☐	☐	☐	☐	☐
(d) After class, I discussed genetics with classmates. - - - - - - - - - -	☐	☐	☐	☐	☐
(e) I think genetics in junior high school is difficult. - - - - - - - - - -	☐	☐	☐	☐	☐
(f) I think it is important to understand genetics. - - - - - - - - - - - -	☐	☐	☐	☐	☐

(2) What are your opinions about GENETICS? *Please tick [∨] a box at each line.*

Interesting	☐	☐	☐	☐	☐	☐	Boring
Related to my life	☐	☐	☐	☐	☐	☐	Unrelated to my life
Difficult	☐	☐	☐	☐	☐	☐	Easy
Too mathematical	☐	☐	☐	☐	☐	☐	Not mathematical enough
Not important	☐	☐	☐	☐	☐	☐	Important

(3) Here are several reasons why genetics is important.
Please tick [∨] THREE boxes which YOU think are the most important.

☐ I will plan to study medicine, biotechnology, or related subjects.
☐ We can understand secrets of human heredity by studying genetics.
☐ We can learn how to calculate probabilities.
☐ It shows the way science works to understand our world.
☐ Genetics is closely linked to our lives.
☐ I need to pass the examination.

(4) Here are several reasons that students want to learn genetics.
Please tick [∨] THREE boxes which best reflect YOUR reasons.

☐ The genetic course is interesting.
☐ It offers good opportunities for useful discussion.
☐ I like the experimental work.
☐ There may be important implications for my life.
☐ I think I can get good performance in biology class.
☐ When I learn a new concept, I gain a sense of achievement.

Figure 8-3: Attitudes questionnaire in this study.

Continued

Part 3: Students' attitudes and opinions about genetics applied in our lives.

(5) Here are some terms which refer to genetics as it might apply in our lives.
Please tick [∨] the boxes which best reflect your situations.

	I have heard of this	I understand the principle involved in this
(a) Human genome project	☐	☐
(b) Genetic counselling	☐	☐
(c) Gene therapy	☐	☐
(d) GM food	☐	☐
(e) Cloning	☐	☐

(6) *Please tick [∨] as many as apply to show where you got information about genetics.*

☐ School (textbook or course)
☐ Internet
☐ General books or magazines
☐ TV programmers or radio
☐ Newspaper or news
☐ Talking to other people

(7) *Please tick [∨] the box which most closely reflects your views:*

	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
(a) Biotechnology will benefit our lives. -	☐	☐	☐	☐	☐
(b) Science research will progress slowly if government imposes strict rules about biotechnology. -	☐	☐	☐	☐	☐
(c) Parents have right to terminate pregnancy when they find the fetus with genetic disease. -	☐	☐	☐	☐	☐
(d) I am willing to buy GM food. -	☐	☐	☐	☐	☐
(e) Cloning should be allowed to help cure diseases. - - - - - - - - - - - - - - - -	☐	☐	☐	☐	☐
(f) It would be good to clone very talented people for the benefit of society.	☐	☐	☐	☐	☐

Please give your honest views of ALL questions.

(8) What advice would you offer to a family when it was found that their unborn child was carrying a serious genetic disease? *Write three sentences only.*

(9) What are the advantages and disadvantages of GM food in our consumer market? *Write three sentences only.*

(10) Scientists should be allowed to clone human beings.
In *three sentences*, show why you agree or disagree with this statement.

Figure 8-3: Attitudes questionnaire in this study.

After collecting the data, every student' responses to each question were converted into a code and the data stored in a spreadsheet. Using the spreadsheet, the codes were used to calculate frequencies, percentages, and comparison groups.

8.4 Results and discussions

The main aim of this study is to explore the performance of junior high school students when they have been taught in a way which is consistent with the information processing predictions related to successful learning and also consistent with the evidence about the development of positive attitudes as well as to inspect the positive attitudes development from human developmental perspectives.

First of all, the overall performance is compared between groups who had used the new teaching material or who had been taught in the traditional way. Then the results from the attitudes questionnaire are discussed and the results of the questionnaire from different groups are compared to each other. In discussing the results obtained, each question is shown here in turn, with the data obtained expressed as percentages. All statistical analyses are conducted using actual frequencies.

8.4.1 The performances of students in genetics learning

Table 8-1 and Table 8-2 show the statistical results and comparisons of the experimental group and the control group in junior high school students' achievement in the school formal examination and WAT.

Table 8-2: Statistical results of school examination scores from the experimental group and the control group in junior high school.

	N	Mean	S.D.	t-test
Experimental group	180	56.5	21.4	3.0
Control group	181	50.1	19.7	$p<0.01$

Table 8-3: Statistical results of word association test from the experimental group and the control group in junior high school.

	N	Mean	S.D.	t-test
Experimental group	180	26.9	12.8	6.0
Control group	181	19.3	10.9	$p<0.001$

The data showed that there was a very significant difference in genetics achievement between the mean scores achieved by the experimental group and the control group (school examination is $t=3.0$, $p<0.01$ and WAT is $t=6.0$, $p<0.001$). The experimental group performed significantly better than the control group in both school examination and WAT. The p-values of both tests are high and therefore the probability that the results happened by chance are low.

Also, the improvements in the mean scores of these two tests obtained are large (school examination is 6.4 and WAT is 7.6). The effectiveness of the new teaching material has therefore been shown to bring about a marked consistent improvement in students' performance. There is possibility that the material being new and different generated greater interest. However, it is unlikely that this, on its own, would have caused such a big improvement.

There is always a difficulty in changing some aspect of the teaching and learning process in that it is possible that the change, simply by being new, will bring about improvement. In this study, the indicator of performance was the school examination and this was not changed and did not reflect the emphases of the new material. Insights were also gained into the structure of ideas in long-term memory using the word association test. Finally, it was hoped that the questionnaire might offer useful insights into the learning process.

Three features were deliberately used to underpin the design of the new material. Firstly, the material aimed to be attractive for inspiring pupils' learning motivation, such as pictures, multimedia, discussion, group competition, and games. Secondly, the material used many live examples to link to everyday experience enabling pupils to build on existing knowledge and enabling them to assimilate and transfer new learning into the long-term memory. Finally, by carefully sequencing the ideas introduced, presenting them step by step, and using learners' language by setting them to interact in groups, the aim was to avoid situations where the amount of information to be handled at any one time exceeded the working memory capacity of the learners.

8.4.2 Questionnaire analyses: the experimental group and the control group

In this section, the results of attitudes questionnaire from junior high school students, which include both the experimental and control group, are going to be presented and discussed one by one.

Table 8-4: The responses of question 1 of attitudes questionnaire from the experimental group and the control group in junior high school.

%	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree	χ^2
(a) I enjoyed the genetics course.	11 14	42 32	34 30	6 13	7 11	18.2 (df4) p<0.01
(b) There is too much to learn in the genetics course.	13 18	23 22	38 43	21 10	5 7	27.9 (df4) p<0.001
(c) I can understand genetics in the class.	9 16	35 29	40 37	9 13	7 5	10.2 (df4) p<0.05
(d) After class, I discussed genetics with classmates.	6 8	16 13	35 40	24 21	19 18	3.9 (df4) No sig.
(e) I think genetics in junior high school is difficult.	16 14	14 16	40 39	21 20	9 11	1.5 (df4) No sig.
(f) I think it is important to understand genetics.	22 25	45 39	23 23	8 6	2 7	5.5 (df3) No sig.

Upper data of each question is the responses of the experimental group (N=180).
Lower data of each question is the responses of the control group (N=181).

It is encouraging that, in both groups around 50% of students had enjoyed the genetics course (those who expressed any form of agreement) (Table 8-3, question 1-a). It revealed again that students like genetics even though it is one of the most difficult parts of biology. However, the experimental group tended to enjoy the genetics course more, with fewer expressing a negative view (significant at <0.01). The aim was that the new teaching material was designed to inspire learning motivation in students by using different teaching techniques.

The result of question 1-b showed that around 40% students thought genetics course involves too much to learn. This is a problem inherent in genetics. Comparing the experimental group and the control group, more students in the control group thought the genetics course was too much to learn. The new teaching material, in fact, covered the same ground. However, the students in the experimental group perceived it as less to learn. This may reflect the way the new material deliberately tried to avoid information overload by introducing the ideas in a step by step way and the way they learned from working with each other.

In the question 1-c, the pattern of difference between two groups is quite complex. The experimental group tended to agree more or be neutral. However, less of them strongly agreed. Perhaps, quite a few of the experimental group were more confident that they understood genetics than the control group students, with some of the experimental group being more realistic: they appreciated more that genetics is difficult.

From question 1-d, it shows that students did not usually discuss the concepts that they learned in the class with their classmates. This is typical of Chinese culture. Also, the schedule in junior high school of Taiwan is too tight and the competition is very intense, so students tend to study by themselves. However, many themes from genetics should be discussed in that there are large social implications.

The pattern from question 1-e suggested that the syllabus was about the right level of difficulty. It is also interesting to note that the new material was not perceived as easier. In fact, there was no intention to make it easier. The aim was to make understanding more likely.

Table 8-5: The responses of question 2 of attitudes questionnaire from the experimental group and the control group in junior high school.

2. What are your opinions about genetics?

	%							χ^2
(a) Interesting	28 26	26 16	25 20	11 17	3 4	7 17	Boring	31.1 (df5) p<0.001
(b) Related to my life	24 40	31 15	26 24	10 8	1 5	8 8	Unrelated to my life	41.4 (df4) p<0.001
(c) Difficult	18 34	19 14	30 26	14 14	8 5	10 7	Easy	21.3 (df5) p<0.001
(d) Too mathematical	12 18	12 13	42 30	18 25	6 5	10 9	Not mathematical enough	17.5 (df5) p<0.01
(e) Not important	4 9	8 6	14 10	27 24	20 13	27 38	Important	16.4 (df4) p<0.01

Upper data of each question is the responses of the experimental group (N=180).
Lower data of each question is the responses of the control group (N=181).

Genetics should be interesting in that it has implications of enormous importance for everyone. However, genetics by its nature is complex, especially at the initial stages of learning. It is possible that the responses for both groups reflected these two perspectives (question 2-a). The data was a descending line from interesting to boring, except the last column and some of both groups' students had strong negative feeling about genetics, especially in the control group (17%).

Comparing the two groups, more students in the experimental group thought genetics was interesting than students in the control group. Clearly, it is possible that the teaching material had affected students' feelings about the subject. This result can be related to question 1-a. There may be three reasons. The use of group work may have been a welcome change from the more lecture type presentation normally used. The teaching material deliberately tried to minimize the demand on the working memory. This may have made the material more accessible to the pupils and learning may have been more satisfying and less dependent on rote memory. The use of relevant applications (a feature of the new material) is known to be attractive to pupils (Reid and Skryabina, 2002a; b).

The result of question 2-b shows some unexpected patterns. It is clear that the pupils selecting the two left hand boxes were identical for both groups (55%). However, the pupils in the experimental group were less confident in their agreement. Perhaps, the new teaching material had raised large social issues which were not readily obvious as related to these pupils' life style at their age.

The question 2-c is the same as question 1-e, but the results are not all the same. Firstly, there are five degree of an answer in the question 1 provided for students and six degree in the question 2. Adding up the middle two answers of question 2, the result showed that 40% students' feelings were neutral, which was the same as question 1-e; even so, they tended to think genetics was difficult in both of groups. On the other way, adding up the three left answer boxes, around 70% of students in two groups thought genetics is difficult, but checking the right answer boxes, that experimental students felt genetics was easier is slightly more (6%). Moreover, 34% of students in the control group thought genetics was very difficult for them and it is much higher than the experimental group. Unlike question 1-e, the experimental group is different from the control group in seeing genetics as less difficult. It is possible that, in question 1-e, the control group is being over positive, seeking to offer responses that will not offend their teachers. In this question, there is no reference to the junior high school course.

Compared with other sections in biology, genetics needs more calculations for finding out the possibilities of heredity. From question 2-d, the data showed students tended to choose columns on the left. Comparing both groups, more control group students felt genetics was too mathematical than experimental students. The traditional teaching contained many calculations that let students known the possibilities of heredity through repeated practice. In the new material, the purpose of the calculations was clearer.

However, the fourth box shows a drop for the experimental group compared to the control group. It is the third box which has grown for the experimental group. Perhaps there was a satisfaction in repetitive calculations when right answers could be obtained. It is worth noting that both groups showed a minority who held strong views that they wanted more mathematics. This might simply reflect those who had a strong interest in that subject.

In the question 2-e, while most of students agreed genetics was important, the experimental group showed less extreme views. It could be extremism related to ignorance or to lack of understanding. Hence, the experimental group moves to the centre. Perhaps, understanding leads to greater respect and balanced views.

Table 8-6: The responses of question 3 of attitudes questionnaire from the experimental and the control group in junior high school.

3. Why genetics is important?	%	χ^2
(a) I will plan to study medicine, biotechnology, or related subjects.	45 44	No sig.
(b) We can understand secrets of human heredity by studying genetics.	86 79	p<0.05
(c) Genetics is closely linked to our lives.	66 67	No sig.
(d) We can learn how to calculate probabilities.	19 28	p<0.01
(e) It shows the way science works to understand our world.	61 55	No sig.
(f) I need to pass the examination.	23 28	No sig.

Upper data of each question is the responses of the experimental group (N=180).
Lower data of each question is the responses of the control group (N=181).

There was an interesting finding that around 45% of students in Taiwan will plan to study a subject related to genetics. Otherwise, 28% of students of the control group and 23% of students of the experimental group thought genetics is important because they need to pass the examination. The control group's students seem more focus on how to calculate probabilities when they studied genetics (28% to 19%).

If the groups choosing (a) and (c) are removed (these show no differences at all) and the other groups are analysed, a chi-square value of 9.5 (df3) is obtained, significant at <0.05. This suggests that the experimental group value more highly the place of genetics in understanding human heredity and the way science works while the control group is thinking more of probabilities and passing exams.

Table 8-7: The responses of question 4 of attitudes questionnaire from the experimental group and the control group in junior high school.

4. The reasons that students want to learn genetics.	%	χ^2
(a) The genetic course is interesting.	51 45	No sig.
(b) It offers good opportunities for useful discussion.	49 46	No sig.
(c) I like the experimental work.	52 56	No sig.
(d) There may be important implications for my life.	63 58	No sig.
(e) I think I can get good performance in biology class.	23 27	No sig.
(f) When I learn a new concept, I gain a sense of achievement.	62 68	No sig.

Upper data of each question is the responses of the experimental group (N=180).
Lower data of each question is the responses of the control group (N=181).

Generally, students wanted to learn genetics because the course is useful for their life and they can get something from the class. Also the experimental work is one of the important parts for students to study science. Clearly, they like the experimental work. However, it is unlikely that pupils are seeing the experimental work as the method of science but the do see it as an enjoyable time. As shown in Table 8-6, even though there are no significant differences between the experimental group and the control group, it still could find the clue to the positive influence of the new teaching material, e.g. interesting (4-a), useful discussion (4-b), and important for the life (4-d).

Table 8-8: The responses of question 5 of attitudes questionnaire from the experimental group and the control group in junior high school.

5. Here are some terms which refer to genetics as it might apply in our lives.

%	Never heard	Heard before	Understand	χ^2
(a) Human genome project	8 7	71 78	21 15	No sig.
(b) Genetic counselling	2 1	58 52	40 47	$p<0.05$
(c) Gene therapy	2 3	69 72	28 25	No sig.
(d) GM food	0 1	60 56	40 43	$p<0.001$
(e) Cloning	1 0	58 56	41 44	$p<0.05$

Upper data of each question is the responses of the experimental group (N=180).
Lower data of each question is the responses of the control group (N=181).

In general, almost all of the students had heard these applied genetics terms, which often appeared on the mass media. Around 40% of students chose/thought they understand these terms, which also showed on the results of the question 1-c. School is an important source that students gain genetics knowledge. To review the curriculum, both human genome project and gene therapy are mentioned less than other issues, so the data show the same results.

Table 8-9: The responses of question 6 of attitudes questionnaire from the experimental group and the control group in junior high school.

6. Where did you get information about genetics?	%	χ^2
(a) School (textbook or course)	29 29	No sig.
(b) Internet	16 17	No sig.
(c) General books or magazines	15 14	No sig.
(d) TV programmers or radio	15 15	No sig.
(e) Newspaper or news	16 16	No sig.
(f) Talking to other people	9 9	No sig.

Upper data of each question is the responses of the experimental group (N=180).
Lower data of each question is the responses of the control group (N=181).

There are no differences between the experimental group and the control group. The results showed that school is an important resource for junior high school students in Taiwan and talking to other people is not a major method to get their genetic knowledge.

Table 8-10: The responses of question 7 of attitudes questionnaire from the experimental group and the control group in junior high school.

%	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree	χ^2
(a) Biotechnology will benefit our lives.	19 23	40 40	36 29	2 5	3 3	6.6 (df3) p<0.05
(b) Science research will progress slowly if government imposes strict rules about biotechnology.	3 8	15 9	47 46	22 24	13 13	0.6 (df3) No sig.
(c) Parents have right to terminate pregnancy when they find the fetus with genetic disease.	17 22	25 27	32 30	17 13	9 8	5.5 (df4) No sig.
(d) I am willing to buy GM food.	3 3	8 14	60 45	17 21	11 17	19.1 (df4) p<0.001
(e) Cloning should be allowed to help cure diseases.	10 18	18 32	34 32	22 10	16 8	53.2 (df4) p<0.001
(f) It would be good to clone very talented people for the benefit of society.	5 12	9 13	24 29	18 16	44 29	25.4 (df4) p<0.001

Upper data of each question is the responses of the experimental group (N=180).
Lower data of each question is the responses of the control group (N=181).

On the whole, students in the experimental group were more conservative. For example, in the question 7-a, although around 60% of students in both groups agreed that biotechnology will benefit our lives, there is a trend for the experimental group to move in towards the central position. It is possible that they were exposed to several social issues about genetics and realized the realities. In addition, students in the experimental group thought about ethic and moral issues more. From the question 7-c, although there is no significant difference between two groups, there does seem to be a pattern. The control group tends to go to left side and the experimental group tends to go to right. Perhaps, the latter seems to consider the ethic more, and not only see the problem itself. It is because that the new teaching material gave students more chances to think about ethics which was a lack in the traditional teaching.

In addition, it is worth noting that the experimental group students doubted if they will buy GM food, but the control group students tended to be even more hesitant. The experimental group strongly disagreed about cloning very talented people to benefit the society. Only 35% of students believe government has good intentions to the society.

Table 8-10, Table 8-11, and Table 8-12 show the results of three open questions. In each of open questions, the students' responses were grouped in categories (labelled (a), (b),

(c) etc). In the three tables below, the categories are listed under the question and the percentages of the students who gave a comment which fitted the categories are shown. The column marked 'Total answer' is the sum of students' responses for each group.

Table 8-11: The responses of question 8 of attitudes questionnaire from the experimental and the control group in junior high school.

8. What advice would you offer to a family when it was found that their unborn child was carrying a serious genetic disease?
   (a) Give up (abortion/throw it away/reject).
   (b) Treat this disease or take care this child to reduce the symptoms of genetic disease as much as they can.
   (c) That is life and it has right to live.
   (d) Go to see a doctor/consultant.
   (e) The child carrying a serious genetic disease needs lots of money to take care of them, so it depends on money.
   (f) Pray.

%	a	b	c	d	e	f	Total answer
Experimental group	46	29	5	18	1	1	297 (1.65/person)
Control group	56	30	4	8	2	0	276 (1.52/person)
X^2	p<0.001	No sig.	-	p<0.001	-	-	

Upper data of each question is the responses of the experimental group (N=180).
Lower data of each question is the responses of the control group (N=181).
'-' means the data is too small to calculate.

Table 8-12: The responses of question 9 of attitudes questionnaire from the experimental and the control group in junior high school.

9. What are the advantages and disadvantages of GM food in our consumer market?
   (a) Plants are stronger, better able to grow.
   (b) Cheap.
   (c) Another choice.
   (d) Delicious/added nutrition.
   (e) We are not sure if it is harmful to health.
   (f) It may affect the market of original food.
   (g) It is not natural.

%	a	b	c	d	e	f	g	Total answer
Experimental group	11	8	6	24	42	9	0	281 (1.56/person)
Control group	8	10	18	22	32	9	1	210 (1.16/person)
X^2	No sig.	No sig.	p<0.001	No sig.	p<0.001	No sig.	-	

Upper data of each question is the responses of the experimental group (N=180).
Lower data of each question is the responses of the control group (N=181).
'-' means the data is too small to calculate.

Table 8-13: The responses of question 10 of attitudes questionnaire from the experimental and the control group in junior high school.

10. Scientists should be allowed to clone human beings. Why do you agree or disagree with this statement?
    (a) To help cure disease/donate organ.
    (b) Clone very talented people for the benefit of society.
    (c) We can ask cloning human to work/fight for us.
    (d) Provide for science research to improve our knowledge or technology.
    (e) May cause some social problems, ex: crimes, population increased, human is substituted, resource competition.
    (f) Ethic problems (moral, religion, or human right).

%	a	b	c	d	e	f	Total answer
Experimental group	19	8	10	3	30	30	173 (0.96/person)
Control group	14	15	13	5	30	23	168 (0.93/person)
χ^2	$p<0.05$	$p<0.01$	No sig.	-	No sig.	$p<0.05$	

Upper data of each question is the responses of the experimental group (N=180).
Lower data of each question is the responses of the control group (N=181).
'-' means the data is too small to calculate.

Taking the three open-ended questions together, the experimental group offered over 750 responses which was almost 100 more than the control group (of more or less identical size). This suggests that the students who had undertaken the new teaching approach were developing more ideas and opinions related to societal issues derived from genetics.

Also, it could be found that the experimental group students seemed more realistic and more concerned about ethical problems. For example, the control group supported to give up the unborn child more when a family found the child carrying a serious genetic disease. On the other hand, more students in the experimental group suggested the family go to see a doctor/consultant to get more information before they make any decision. Moreover, the experimental group students more doubted if GM food is harmful to health and the control group students agreed more to clone very talented people for the benefit of our society (the findings are consistent with question 7).

8.4.3 Questionnaire analyses: students from the different age groups

The attitudes questionnaire was used with three different age groups: undergraduates, senior high school students, and junior high school students. As mentioned before, unless a student chooses to take a biology course, then they will receive no more genetics instruction after junior high school. Thus, the aim here was to explore the way attitudes change with age.

It should be noted that the questionnaire for undergraduates and senior high school students is slightly different by taking out some questions due to time being limited. For comparing three age groups, all the question number followed the questionnaire for junior high school students.

Table 8-14: The responses of question 2 of attitudes questionnaire from undergraduates, senior high school students, and junior high school students.

2. What are your opinions about genetics?								
	%							χ^2
(a) Interesting	25 18 26	15 13 16	38 29 20	10 15 17	6 9 4	6 16 17	Boring	30.3 (df5) p<0.001 13.8 (df4) No sig. 50.8 (df4) p<0.001
(b) Related to my life	28 35 40	29 23 15	28 22 24	9 13 8	4 3 5	2 4 8	Unrelated to my life	10.8 (df4) p<0.05 20.3 (df4) p<0.001 40.5 (df4) p<0.001
(c) Difficult	20 28 34	22 22 14	37 32 26	15 13 14	3 2 5	3 3 7	Easy	7.8 (df4) No sig. 18.2 (df4) p<0.01 34.6 (df4) p<0.001
(d) Too mathematical	10 14 18	24 14 13	33 32 30	22 27 25	7 9 5	4 4 9	Not mathematical enough	24.6 (df5) p<0.001 2.3 (df4) No sig. 28.8 (df4) p<0.001
(e) Not important	6 7 9	8 10 6	18 21 10	35 29 24	24 17 13	9 16 38	Important	16.8 (df5) p<0.01 58.8 (df5) p<0.001 95.5 (df5) p<0.001

Upper data of each question is the responses of undergraduates (N=209). Middle and lower data is the responses of senior high school students (N=188) and the control group of junior high school students (N=181).
The first chi-square result is comparing undergraduates with senior high school students, the second is comparing senior high school students with junior high school students, and the last one is comparing junior high school students with undergraduates.

Form the responses of question 2-a, it is known that genetics is an interesting topic for all age groups students, even though many studies showed it is one of the most difficult topics in biology. Thus, difficulties here do not affect many students' feelings about genetics.

Comparing among the groups (question 2-a), juniors felt more bored with genetics than elders. It may be that junior high school students just finished genetics course and this part of biology is a new topic for them. As mentioned before, genetics nature is with many terms, abstract concepts, and the level of organisation so pupils' interests may decrease after learning. On the other hand, elders have learnt and experienced the genetics applications in life more, so they think it is more interesting.

In addition, the pattern of responses from junior high school and senior high school students tended to be more polarised: they tended to hold more strong views, both positive and negative. Nonetheless, the school groups' views seemed more immature, showing strong likes and dislikes for people and things. The feelings of university students are more moderate. This is understandable in that, being older, they know more and tend to think more deeply.

In question 2-b, 80% of students agreed that genetics is related to their lives. This is most marked for junior high school pupils. Younger students seem to see things direct and simple so their opinions are more extreme. There is tendency to move towards the middle (strictly box two and three) as students become older. It is believed that judgment matures with age and that they are more able to see situations from many perspectives.

The results of question 2-c showed that all age groups thought genetics is difficult. However, a small portion of the sample of junior high school students loved biology and were able to gain a good performance in examinations, showing that it is not a difficult subject for them.

Many students seem to be left with the impression that genetics is all about using probability calculations to predict trait combinations of coming generations. If students enjoy finding out the possibilities of a child's characteristics, they may want more mathematics. However, the younger students find the mathematics more of a problem.

Furthermore, around 70% of students agree genetics is important. As we see in Table 8-13, question 2-e, 38% of junior high school students thought genetics extremely related to their future which is much higher than other two groups. In addition, the longer students are away from the course, the less important the subject may become. In fact, despite their importance, many people still ignore issues in genetics (see Table 8-16).

Table 8-15: The responses of question 3 of attitudes questionnaire from undergraduates, senior high school students, and junior high school students.

3. Why genetics is important?	%	χ^2
(a) I will plan to study medicine, biotechnology, or related subjects.	37 48 44	p<0.001 No sig. No sig.
(b) We can understand secrets of human heredity by studying genetics.	92 86 79	No sig. No sig. p<0.001
(c) Genetics is closely linked to our lives.	72 67 67	No sig. No sig. No sig.
(d) We can learn how to calculate probabilities.	13 15 28	No sig. p<0.001 p<0.001
(e) It shows the way science works to understand our world.	73 59 55	p<0.001 No sig. p<0.001
(f) I need to pass the examination.	12 25 28	p<0.001 No sig. p<0.001

Upper data of each question is the responses of undergraduates (N=209). Middle and lower data is the responses of senior high school students (N=188) and the control group of junior high school students (N=181).

The first chi-square result is comparing undergraduates with senior high school students, the second is comparing senior high school students with junior high school students, and the last one is comparing junior high school students with undergraduates.

It is surprising that around 45% of students in Taiwan are planning to study genetics related subjects. In addition, it is found that the steady rise in choices (b) and (e) reflects increasing maturity. (d) and (f) are obviously less important as the students are older. It could be explained that the senior students' value more highly the place of genetics in understanding human heredity and the way science works while the junior students think more of probabilities and passing exams.

Table 8-16: The responses of question 4 of attitudes questionnaire from undergraduates, senior high school students, and junior high school students.

4. The reasons that students want to learn genetics.	%	χ^2
(a) The genetic course is interesting.	52 44 45	p<0.01 No sig. p<0.05
(b) It offers good opportunities for useful discussion.	48 47 46	No sig. No sig. No sig.
(c) I like the experimental work.	42 45 56	No sig. p<0.001 p<0.001
(d) There may be important implications for my life.	71 80 58	p<0.001 p<0.001 p<0.001
(e) I think I can get good performance in biology class.	12 23 27	p<0.001 No sig. p<0.001
(f) When I learn a new concept, I gain a sense of achievement.	76 62 68	p<0.001 No sig. p<0.01

Upper data of each question is the responses of undergraduates (N=209). Middle and lower data is the responses of senior high school students (N=188) and the control group of junior high school students (N=181).

The first chi-square result is comparing undergraduates with senior high school students, the second is comparing senior high school students with junior high school students, and the last one is comparing junior high school students with undergraduates.

The older students are perhaps more aware of the important implications for life (d) and, more aware of their feelings of achievement (f). The decline in (c) with age fits the general pattern. Younger students like experimental work more and want to do by their own hands and play. They may see the experimental work as the method of science or see it as an enjoyable time. (e) shows that the younger age group care more about the school examination scores. This might be caused by the national examination system of Taiwan or parents and teachers put emphasis on students' performance.

Table 8-17: The responses of question 5 of attitudes questionnaire from undergraduates, senior high school students, and junior high school students.

5. Here are some terms which refer to genetics as it might apply in our lives.

%	Never heard	Heard before	Understand	χ^2
	18	73	9	$p<0.05$
(a) Human genome project	19	68	13	$p<0.001$
	7	78	15	$p<0.001$
	8	77	15	$p<0.001$
(b) Genetic counselling	2	72	26	$p<0.001$
	1	52	47	$p<0.001$
	12	75	13	No sig.
(c) Gene therapy	11	72	17	$p<0.001$
	3	72	25	$p<0.001$
	3	77	20	No sig.
(d) GM food	5	71	24	$p<0.001$
	1	56	43	$p<0.001$
	3	77	20	$p<0.001$
(e) Cloning	1	73	27	No sig.
	0	56	44	$p<0.001$

Upper data of each question is the responses of undergraduates (N=209). Middle and lower data is the responses of senior high school students (N=188) and the control group of junior high school students (N=181).
The first chi-square result is comparing undergraduates with senior high school students, the second is comparing senior high school students with junior high school students, and the last one is comparing junior high school students with undergraduates.

Generally, most of students seem familiar with these genetic terms. It is quiet remarkable that more junior high school students said they understand the terms. This group has just completed their genetics course and much would remain fresh in their minds. However, it is a matter of concern that the older groups were less sure of understanding. They had been taught the same course when younger but, perhaps, much had by now been forgotten. This raises the question about the effectiveness of their education in this area of biology (mainly, scientific literacy) although a possible explanation might be that some of the topics were not covered in such detail simply because much less was known from biological research at the time when they were being taught.

Table 8-18: The responses of question 6 of attitudes questionnaire from undergraduates, senior high school students, and junior high school students.

6. Where did you get information about genetics?	%	χ^2
(a) School (textbook or course)	15 26 29	p<0.001 No sig. p<0.001
(b) Internet	22 17 17	No sig. No sig. No sig.
(c) General books or magazines	16 13 14	No sig. No sig. No sig.
(d) TV programmers or radio	17 17 15	No sig. No sig. No sig.
(e) Newspaper or news	23 21 16	No sig. No sig. p<0.05
(f) Talking to other people	7 7 9	No sig. No sig. No sig.

Upper data of each question is the responses of undergraduates (N=209). Middle and lower data is the responses of senior high school students (N=188) and the control group of junior high school students (N=181).
The first chi-square result is comparing undergraduates with senior high school students, the second is comparing senior high school students with junior high school students, and the last one is comparing junior high school students with undergraduates.

Generally, students in Taiwan get information about genetics are from school (a), internet (b), and newspaper or news (e), but talking to other people (f) is seldom the way to get the information. Around 60% of students in Taiwan use a computer as a medium to gain genetics knowledge. It suggests that most pupils know not only how to manipulate a computer but also how to take the information they want through the internet.

Comparing all of them, juniors rely on school teachers more to give them information. That means school education plays the important part of transmitting science knowledge. However, undergraduate students take the initiative in gaining information such as internet, newspaper and news. It might be because undergraduates are more independent and concerned about current events or their studies are more specific and professional those are not related genetics so it is hard to get any information about genetics in the university.

Table 8-19: The responses of question 7 of attitudes questionnaire from undergraduates, senior high school students, and junior high school students.

%	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree	χ^2
(a) Biotechnology will benefit our lives.	26 21 23	62 58 40	12 19 29	0 2 5	0 0 3	9.5 (df2) p<0.01 27.6 (df2) p<0.001 57.4 (df2) p<0.001
(b) Science research will progress slowly if government imposes strict rules about biotechnology.	6 6 8	18 17 9	49 48 46	22 25 24	5 4 13	0.3 (df3) No sig. 18.7 (df3) p<0.001 29.8 (df4) p<0.001
(c) Parents have right to terminate pregnancy when they find the foetus with genetic disease.	25 17 22	45 36 27	22 33 30	7 11 13	1 3 8	23.6 (df3) p<0.001 13.7 (df3) p<0.01 47.4 (df3) p<0.001
(d) I am willing to buy GM food.	6 5 3	20 20 14	48 51 45	19 17 21	7 7 17	0.7 (df3) No sig. 20.1 (df3) p<0.001 21.3 (df3) p<0.001
(e) Cloning should be allowed to help cure diseases.	11 13 18	37 35 32	33 32 32	12 10 10	7 10 8	3.1 (df4) No sig. 3.4 (df4) No sig. 8.6 (df4) No sig.
(f) It would be good to clone very talented people for the benefit of society.	6 6 12	10 11 13	25 27 29	32 24 16	27 32 29	8.2 (df4) No sig. 13.9 (df4) p<0.01 42.0 (df4) p<0.001

Upper data of each question is the responses of undergraduates (N=209). Middle and lower data is the responses of senior high school students (N=188) and the control group of junior high school students (N=181).

The first chi-square result is comparing undergraduates with senior high school students, the second is comparing senior high school students with junior high school students, and the last one is comparing junior high school students with undergraduates.

As they get older, more of them agree that biotechnology will benefit our lives (question 7-a). The answers are more scattered with the younger group. Actually, although the aim of biotechnology is to benefit our lives, scientists are often uncertain about the effects after they modify the cells/organisms. Because the junior high school students had just finished their genetics course when they answered this questionnaire and the genetic issues were still fresh in the memory, they might have had have doubts about the results of biotechnology.

About question 7-b, we know that government/organisation seeks to legislate for the benefit of people. For example, the World Health Organisation (WHO) had resolved to prohibit cloning human beings to avoid many ethical and social problems but, from a science point of view, science research thus progresses slowly. The result showed that the undergraduates are more aware that strict rules set by government are needed, perhaps being more conscious that governments have responsibilities to legislate to ensure benefits and safety. However, junior high school students tended to disagree or show more extreme views. Again, it may be that youngers usually have strong feelings and elders tend to think more deeply, with the benefit of age and experience.

In question 7-c, there is a tendency to increased agreement with age. Perhaps, as they become older, there is an increased awareness of realistic. In question 7-d, junior high school students are less willing to buy GM food compared to the other two groups. It shows again the new learning does bring in positive effect.

Considering cloning, students in the university and senior high school had the same pattern of their attitudes about cloning human beings. Comparing with junior high school students, the elder students tended to disagree to clone very talented people for the benefit of society, and junior high school students' opinions were average in different items, so higher percentage of them believed it would be good to clone very talented people. It depended what point of view students thought. If people consider the benefit of society, cloning talented human definitely can contribute more. However, it can be considered to disobey natural rules, species move towards unity, and may cause some social and ethic problems.

Overall, although there are several significant differences, the changes in views are not dramatic. Perhaps, social attitudes relating to genetics develop quite young and then only move to a small extent later. It is also possible that parental attitudes are powerful and generate a relatively stable set of views.

The following two tables are the results from the open questions, which students responses were grouped in categories (Table 8-19 and Table 8-20). In the tables, the categories are listed under the question and the percentages of the pupils who gave a comment which fitted the categories are shown. The column marked 'Total answer' is the sum of students' responses for each part.

Table 8-20: The responses of question 8 of attitudes questionnaire from undergraduates, senior high school students, and junior high school students.

8. What advice would you offer to a family when it was found that their unborn child was carrying a serious genetic disease?
   (a) Give up (abortion/throw it away/reject).
   (b) Treat this disease or take care this child to reduce the symptoms of genetic disease as much as they can.
   (c) That is life and it has right to live.
   (d) Go to see a doctor/consultant.
   (e) The child carrying a serious genetic disease needs lots of money to take care of them, so it depends on money.
   (f) Pray.

%	a	b	c	d	e	f	Total answer
Undergraduates	49	33	6	7	5	0	319 (1.53/person)
Senior high school students	55	25	8	9	2	1	251 (1.34/person)
Junior high school students	56	30	4	8	2	0	276 (1.52/person)
χ^2	No sig. No sig. $p<0.05$	$p<0.01$ No sig. No sig.	No sig. - -	No sig. No sig. No sig.	- - -	- - -	

Upper data of each question is the responses of undergraduates (N=209). Middle and lower data is the responses of senior high school students (N=188) and the control group of junior high school students (N=181).

The first chi-square result is comparing undergraduates with senior high school students, the second is comparing senior high school students with junior high school students, and the last one is comparing junior high school students with undergraduates.

'-' means the data is too small to calculate.

Table 8-21: The responses of question 10 of attitudes questionnaire from undergraduates, senior high school students, and junior high school students.

10. Scientists should be allowed to clone human beings. Why do you agree or disagree with this statement?
   (a) To help cure disease/donate organ.
   (b) Clone very talented people for the benefit of society.
   (c) We can ask cloning human to work/fight for us.
   (d) Provide for science research to improve our knowledge or technology.
   (e) May cause some social problems, ex: crimes, population increased, human is substituted, resource competition.
   (f) Ethic problems (moral, religion, or human right).

%	a	b	c	d	e	f	Total answer
Undergraduates	17	7	2	6	26	42	271 (1.30/person)
Senior high school students	11	12	2	5	35	35	167 (0.89/person)
Junior high school students	14	15	13	5	30	23	168 (0.93/person)
χ^2	No sig. No sig. No sig.	No sig. No sig. $p<0.01$	- - -	- - -	$p<0.001$ No sig. No sig.	$p<0.05$ $p<0.001$ $p<0.001$	

Upper data of each question is the responses of undergraduates (N=209). Middle and lower data is the responses of senior high school students (N=188) and the control group of junior high school students (N=181).

The first chi-square result is comparing undergraduates with senior high school students, the second is comparing senior high school students with junior high school students, and the last one is comparing junior high school students with undergraduates.

'-' means the data is too small to calculate.

Firstly, the undergraduates are more willing to make choices (319 compared to 251 and 276; 271 compared to 167 and 168). Secondly, comparing among three groups, juniors opinions are simple and immature, as might be expected. For example, they supported to give up the unborn child who was carrying a serious genetic disease. They agreed to clone human being because cloned people could do something to benefit society or just because they can ask cloned people to work/fight for them. However, the older students' thinking ways are more positive and realistic. They took money into account when they have to deal with a family with the genetics disease. Also, the oldest group seemed to treat a foetus as a life and tried to deal with the disease as much as they can.

8.5 Conclusions

The new teaching material developed was based on evidence derived from former research. The aim was to improve pupils' learning in genetics, especially conceptual understanding, to develop positive attitudes and growing awareness of the social implications of genetics. The curriculum to be followed and the time allocation could not be changed nor could the teachers be changed. The new materials were deliberately constructed to minimise demands of working memory in that this is known to be a key factor which hinders understanding. They were also designed to relate closely to life and society and to involve the learners in some interaction and discussion over key issues. This approach is known to encourage attitude development (Johnstone and Reid, 1981).

The results demonstrated that the experimental group performed significantly better than the control group in both school examinations and the word association test. Previous work has showed again and again the influence of the working memory on the examination performance (e.g. Hussein, 2006; Danili and Reid, 2004; Colom *et al.*, 2003; Bahar, 1999; Johnstone *et al.*, 1993; Geary and Widaman, 1992; Opdenacker *et al.*, 1990). In this study, the teaching material was deliberately designed to reduce working memory overloading. The results are quite clear and are also consistent with previous work.

Another important factor influencing success in learning relate to attitudes. In general, it is encouraging that around 50% of both the experimental group and the control group from junior high school enjoyed and could understand the genetics course as well as over 60% of students tended to see genetics as interesting, important, and related to their life, even they thought genetics is difficult, too mathematical, and too much to learn. Also, the feelings about genetics for university and senior high school students are similar.

Comparing the experimental group with the control group about their feelings about the genetics course, it was found that pupils who had experienced the new teaching material have evidently improved positive attitudes. The results showed they were more satisfied and realistic. On the other hand, pupils who were taught by the traditional way tended to have more complaints, such as too much to learn, too much mathematics, and boring.

Studying junior students' attitudes and opinions about genetics applied in our lives, the results showed that the experimental group were more conservative and thought more about ethical and moral issues. Moreover, the quantity of answers on the open questions implied that the new teaching material did affect students on developing their attitudes and opinions in genetics related issues.

The minor part of this study was to probe into the attitude development with age. Three different age groups, undergraduates, senior high school students, and junior high school students, were investigated. Regarding the feelings of genetics course and attitudes and opinions about social implications of genetics, juniors' responses were more extreme, direct and immature and elders expressed more conservative and realistic views.

Overall, although the new teaching material had had a significant impact, there is clearly more to be done. Genetics still stands out poorly when compared to other parts of biology. The curriculum in genetics is abstract with much terminology and symbolism. These really have no place in a school syllabus and the students are clearly more perceptive than the curriculum planners. According to Hussein (2006), *a poor curriculum and teaching will tend to generate negative attitudes and this may lead to poor performance in tests and examinations. Good performance in tests and examinations will tend to generate better attitudes. Thus, attitudes and success are highly linked and each affects each other.* The use of the teaching material had clearly generated better attitudes and improved performance. This was an example showing how the application of a well-attested educational model can bring real benefits for the learners.

Chapter Nine

Conclusions and Recommendations

9.1 Introduction

In this chapter, a summary of the findings of this study will be outlined. This will be followed by some discussions on the limitations of this study. Finally, some recommendations on junior high school students' learning genetics as well as suggestions for further work will also be put forward.

9.2 Background to the study

It is important to have clear aims for school science education and for the study of genetics in particular. In fact, science is carried out in school education not only to transmit the knowledge and prepare for advanced study or a possible future carrier, but also to cultivate students to be citizens in modern societies which are now highly dependent upon scientific and technological advances (Kesner *et al.*, 1997). This implies helping students to be interested in and understand the world around them, to engage in the discourses of and about science, to be sceptical and question of claims made by others about scientific matters, and to make informed decisions about the environment and their own health and well-being (Betero, 1997).

Thus, the aim of learning science can be summed up as scientific literacy (AAAS, 1989) and this involves a full understanding about the nature of science, its findings and its social impact (DeBoer, 2000; Norman, 1998). This can be illustrated where there are three aspects to such literacy (Figure 9-1).

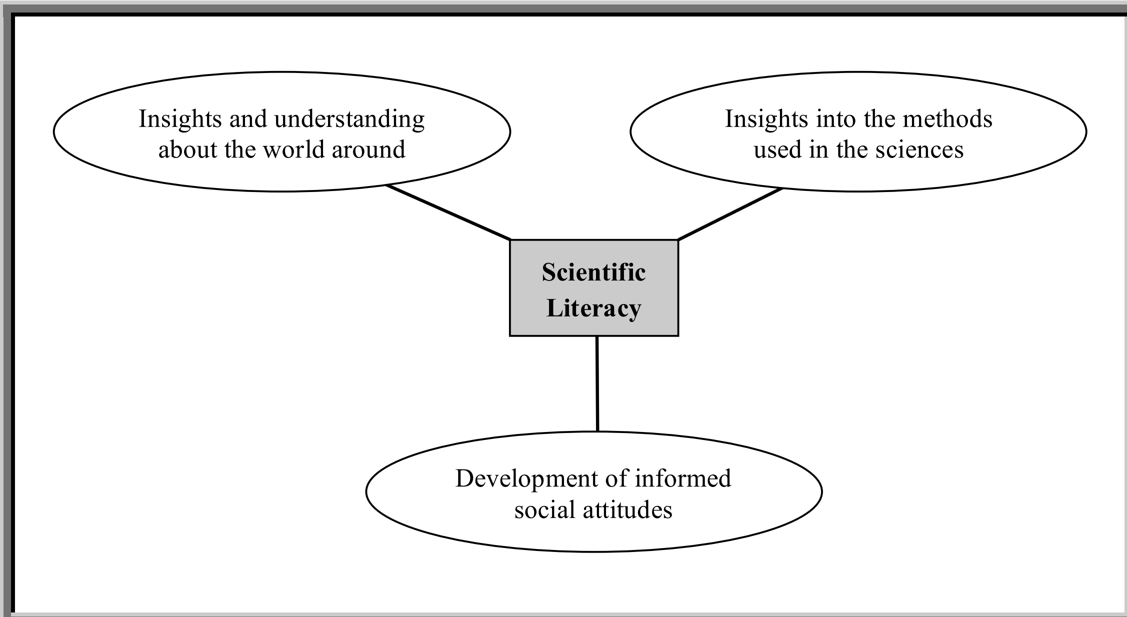


Figure 9-1: Three aspects of scientific literacy.

It is important in school science education to promote a positive attitude towards engaging with science, because attitudes and values established toward science in the early years will shape a person's development of scientific literacy. As Johnstone and Reid (1981) noted, promoting positive attitudes related to students' understanding in the science is a key part of science education.

Considerable research has been focused on how to encourage positive attitudes towards the science subject by choosing the curriculum contents and teaching ways appropriately (e.g. Reid and Skryabina, 2002a; 2002b). People's knowledge, feelings, and experiences may lead to evaluations and this may lead to subsequent decisions. Without interests or motivation in the subject being studied, it is very hard for the learner to keep learning. On the other hand, the literature is replete with practical suggestions and skills deemed necessary to be included in the school curriculum (AAAS, 1989). This has sometimes led to an approach labelled 'Science-Technology-Society'.

Based on student-oriented interactive learning, the STS instruction aims to help students make sense out of their life today and for the future, and does so in ways that support students' natural tendency to integrate their personal understandings of their social, technological and natural environments. It is believed that this kind of approach, in addition to increasing scientific literacy, will also increase positive attitudes and achievement in the science (Mbajiorgu and Ali, 2003). Moreover, it aims to prepare future scientists and citizens alike to participate in a society increasingly shaped by research and development involving science and technology.

However, the fact is that many students claim that science is hard to learn and the understanding of scientific ideas of the majority of students is thought to be very poor. This is also found in genetics learning (Lewis and Wood-Robinson, 2000; Bahar *et al.*, 1999a). Literature reviews about school and university students' difficulties when learning genetics and several major reasons as being problematic were extracted:

1. Genetics subject itself:

- *Nature of scientific knowledge*: Genetics is one of the most dynamic research disciplines within the natural sciences. It is a steady accumulation and might be changing in time and open to debate (Ravetz, 1997; Durkhein, 1914).

- *Alternative conceptions*: Young people use their own intuitive ideas to explain their life experiences, in order to make sense of the world. By the time of receiving formal science education, the prior conceptions are already well established working theories. If these are in conflict with accepted scientific ideas, new learning will be affected and misconceptions may establish, and further, these alternative conceptions and misconceptions will interfere with later study (Johnstone, 1991).

- *Complexity*: In genetics, the complexity exists on the macroscopic, microscopic, molecular, and symbolic level (Johnstone, 1991). When learning the concept which belongs simultaneously to several levels of organisation, considerable difficulty is encountered. It is because several levels of organisation must be integrated in order to understand the processes underlying genetic phenomena and to grasp the overall picture of genetics (Bahar *et al.*, 1999a). In addition, the levels of organisation, sometimes, lie both within a single discipline of the same/different chapter(s) while also involving other disciplines (like mathematics or chemistry).

- *Terminological language*: Language development and conceptual development are inextricably linked. Firstly, understanding science is more than just 'knowing the meaning' of particular words and terms, it is about 'making meaning' through exploring how these words and terms relate to each other (Sutton, 1996). One of the biggest problems of language in genetics is the complex and vast technical vocabulary. Students have the problem of learning the new and abstract words, and at the same time learning new concepts in that vocabulary (Ramorogo and Wood-Robinson, 1995). Moreover, the vocabulary of genetics is not always used consistently or correctly (such as a different meaning in colloquial language and inappropriate metaphors) and therefore can be a source itself in inducing confusion and error (Cho *et al*., 1985).

- *Mathematical requirement*: Bahar *et al*. (1999a) noted that mathematical expressions, which are symbolic, cause problems. In addition, students have difficulties in transferring the mathematical knowledge and insights from one context to another. Although students often understand the probabilistic problems and have no difficulties in determining the chances, they fail when they have to apply the same chance events in the context of genetics (Kinnear, 1983).

2. *Differences in an individual developmental nature and cognitive nature of learning process:*

- *Cognitive development theory*: The child's cognitive development has four stages (Piaget, 1961) but only the last two stages, concrete operational and formal operational, are significant in secondary science education (Johnstone, 1987). The student's ability to deal with abstract concepts in meaningful learning is correlated with his/her level of cognitive development. Many genetics concepts require abstract thinking. Unless the student's has reached the level of formal operational thinking, he/she will not be able to cope adequately with these ideas.

- *Prior knowledge in the meaningful learning*: To learn meaningfully, students must relate new knowledge to what they already know (Ausubel, 1968). The existing knowledge and how it interacts with new knowledge determine the degrees of meaningful learning. If the knowledge to be learned lacks logical meaningfulness and the student lacks the relevant ideas in his/her own cognitive structure, the learning is rote. Rotely learned knowledge is discrete and isolated, usually not related to established concepts, and may soon be forgotten (Ausubel and Robinson, 1969). When a concept is meaningfully understood by establishing relationships with prior knowledge, it is retained much longer, can be built upon to acquire further understanding. On the other hand, the pre-knowledge will interfere with new learning and lead to the establishment of misconceptions, if it is different from scientists accepted (Driver and Oldham, 1986; Fisher, 1985).

- *The information processing model*: During learning, the information from the external environment is first perceived and selected by the perception filter, processed in the working memory, and then assimilated and accommodated into the long-term memory and stored as cognitive structures (Johnstone, 1993). The perception filter selects what information is meaningful to the person, which is critical and influenced by some forces within his/her external environment and internal thoughts (White, 1988; Brunning *et al*., 1995).

  The working memory is a very limited space. It processes selected inputs from the perception filter and interacts with the prior knowledge retrieved from long-term memory in order to make sense. The average working memory capacity for adults (from aged 16) is 7 ± 2 and that the working memory capacity grows on average by one unit for every two years of age up to age 16 (Cowan, 2001; Miller, 1956). It is found to be one of major limiting factors in all learning. Nevertheless, by chunking, it is possible to reduce the load on the working memory although the capacity of the working memory cannot be changed. That means the working memory improves if the pieces of information are familiar, frequently used, or logically related to each other. On the other hand, it can be easily overloaded when the new knowledge is large, unfamiliar, irrelevant or abstract and thus cause learning difficulties (Cassels and Johnstone, 1982).

  The long-term memory is a permanent information repository. The information which has meaning will be stored readily, whereas the meaningless one will tend to be ignored or discarded. The stored data or schemas can be recalled back to help with the new information processing in the perception filter or the working memory when needed (Johnstone, 1997).

- *Field dependence/field independence of cognitive style*: Every individual has his/her preferred way and habitual pattern for learning. Differences that exist in the individual's cognitive structures enable the individual to have different cognitive styles (Witkin, 1978). The ability to select the most important pieces of information, whether they are the most obvious or noticeable, is related to the learner's FD/FI cognitive style. Unfortunately, many studies in science education indicated that those who are found to be field dependent score significantly lower than those who are found to be field independent at secondary school level as well as at university level (e.g. Bahar, 1999).

9.3 The main findings from the study

In the first stage, the adolescent learners' preconceptions about genetics were explored before they move to their first formal genetics course. A total sample of 141 students was drawn from the first year of public junior high school students (aged around 13) in Taiwan. The structural communication grid was used as a diagnostic testing method.

According to the literature reviews and the contexts analysis in genetics, four essential foundational concepts were generalised: structure and function of cells and its organelles, cell divisions (mitosis and meiosis), reproduction, and basic mathematical requirements, especially in the concept of probability. Thus, based on this, the pre-knowledge test of genetics was developed and carried out. The results showed that:

1. The prior knowledge of beginning learners (adolescents) for genetics is generally poor and alternative views and misconceptions are widespread.

2. Among the foundational concepts, understanding about cell divisions was the worst and understanding the meaning of probability was relatively better. It is clear that students had the greatest problem with learning the cell divisions.

3. Even though nearly half of students grasped the basic concept of the cell, they were still showing a lack of basic and clear knowledge about the cell structures involved.

4. Students seemed to be familiar with the genetics terms: gene, DNA, and chromosome, but they often mixed up them. It was speculated that these three terms are highly connected in students mind but quite vague.

5. Among these genetics terms, students showed to be less clear about the concept about gene than DNA and chromosome. It should be due to gene's abstract concept.

6. About students' understanding of cell divisions, the findings confirmed that most students were confused about mitosis and meiosis and even cannot distinguish them. The confusion over word pairs causes the learning difficulties.

7. Students seemed to be able to carry out routine calculations relating to probability with reasonable competence, but applying these ideas to the field of genetics was of considerably greater difficulty.

8. Probability is expressed as percentages and as fraction and the two systems are confusing for the novice learners.

The second stage of research carried out investigations into aspects of the psychological factors influencing learning in genetics. The size of the working memory space and the degree of field dependence were the main point of this study. In order to coordinate with the former part of the study, the same age group of sample was chosen. In addition to the working memory capacity and the FD/FI of the students, the general ideas of genetics before and after the course were probed for the relationships within/among them. The findings were:

1. The average of working memory capacity of aged 13 students is around five, which was consistent with the findings of other research studies.

2. Measurements of extent of FD/FI correlated positively with measurements of working memoery capacity, again consistent with previous studies.

3. Having correct basic knowledge helped students understanding genetics. In other words, the misconceptions or lack of knowledge influenced their genetics learning.

4. Students with high working memory space performed very much better in genetics tests than students with low working memory space.

5. The field independent students tended to have better scores in the genetics examinations than the field dependent students.

6. The field independent students with high working memory capacity achieved better marks in the genetics tests than those who are the field dependent students with low working memory capacity.

Overall, results from this study suggest that, when teaching genetics or planning its teaching materials, teachers should take account of the education and teaching aims, the subjects itself causing difficulties, students' previous knowledge especially in terms of misconceptions, the stage of the students' cognitive development, and the amount of useful information in a learning situation (avoid overloading the working memory capacity) etc.

These findings were applied in the third stage. This sought to develop an instructional approach, which provides teachers/educators with an example, in order to see if it is possible to improve students' learning in genetics. Although restricted by the demands of the national syllabus, the needs of the examinations, the impossibility of training the teachers, and the fixed time allocation, the new teaching materials were designed specifically to improve understanding, to develop positive attitudes, and to encourage increased social awareness of the impact of genetics in the modern society.

The teaching material involved a set of lessons developed for the genetics course of first year of junior high school in Taiwan. The lessons were presented under five themes: basic terminology, theory of heredity, human inheritance, sex determination, and genetics in our lives. Under some limitations of actualities (the curriculum has to be followed and the time allocation could not be changed), it was deliberately constructed to minimise demands of the working memory in that this is known to be a key factor which hinders understanding. It was also designed to relate closely to life and society and to involve the learners in some interaction and discussion over key issues. This approach is known to encourage attitude development (Johnstone and Reid, 1981).

At the end of the course, students were evaluated in terms of performance and attitudes development. The results were:

1. Students who used the teaching material from this study performed better than students who were taught by the traditional way.

2. Generally, students enjoyed and could understand the genetics course. They tended to see genetics as interesting, important, and related to their life, even they thought genetics is difficult, too mathematical, and too much to learn.

3. Students who had experienced the new teaching material have improved positive attitudes and social awareness. They expressed more enjoyment, were more satisfied and realistic and thought more about ethical and moral issues.

4. Students who were taught by the traditional way tended to have more complaints, such as too much to learn, too much mathematics, and boring.

5. The minor part of the third stage was explored the way attitudes change with age. It is found that juniors' responses were more extreme, direct and immature and elders expressed more conservative and realistic views.

Overall, the use of the teaching material had clearly generated better attitudes and improved performance. This was an example to reveal how a well-attested educational model can have real benefits for the learners.

9.4 Limitations of this study

One major limitation to this study was that it was carried out only in Taiwan. The teaching of biology/genetics in junior high school of Taiwan is usually based on the traditional didactic methods, and using an information laden approach. Students are inevitably going to respond positively to a more sensitive approach and this must also be a factor in the remarkable improvement in performance and attitudes development. Thus, it would be interesting to know whether the findings from this study would be similar if conducted in other countries (e.g. Scotland).

In addition, students were taught in Mandarin and this poses all kinds of problems with the translations and symbols are used. This will place demands on the working memory even though care was taken in presenting these areas.

Furthermore, the syllabus and the time allocation could not be changed and the total content was, therefore, more or less the same. However, the way of the new teaching material was presented very differently. Specially, the new material was carefully linked on to pre-knowledge which the students should have possessed and placed emphasis on those parts where students often or easily have misconceptions. In addition, it was presented to avoid working memory being overloaded. Multiple approaches were adopted to communicate key ideas, such as pictures, tables, discussions, multimedia as well as texts. Moreover, language was kept simple and accessible. Very often, students were set to interact in small groups in which they work together to maximise their own and each other's learning and lead to their own improved understanding and learning motivation. However, some of approaches alone will have had its own impact although it is known that it does not bring benefits to all students (Young, 2000).

The evaluation was carried out when the students had just finished the genetics course. Thus, the performance might arguably include some rote learning. It would be interesting to assess their performance after a couple of months or even longer in order to minimise the effect of rote learning.

In addition, the information this study collected is all quantitative data from paper-pen tests. The investigation would have been enriched using the qualitative research, such as interview. However, due to time and organisational constraints, these could not be carried out.

The new teaching material used in this study was a set of lessons and they were carried out as one approach change for the experimental group students. Even though an overwhelming majority of the students appeared to favour the approach and performed better in the traditional examinations, the conclusions could only be drawn about the superiority of the whole teaching material over the traditional method. If the lessons are used separately and then students are evaluated their responses by each lesson, it might provide the detail information about the effectiveness of the new teaching material in helping the students to learn genetics.

However, it has not been the intention in this study to present a teaching material that guarantees good results in all circumstances. Obviously, many factors influence the success or failure of a teaching material, among them possession of school funds and equipments, education policy maker support, and the adaptation of both teachers and students to a new way of teaching and learning, among others.

9.5 Recommendations for junior high school students in learning genetics

In the light of the findings of the present research, the following strategies are recommended for implementation in genetics course of junior high school:

1. Attractive teaching material is a universal way for inspiring learning motivation.

2. Students' prior knowledge often does not conform to scientifically accepted principles and these ideas may serve as a foundation upon which new learning may be built. Obviously, these ideas should be taken into account by teachers; if they are not, and if they are erroneous, they could interfere with new learning. The results from this study can serve to help teachers plan more effectively and to select the best ways for introducing learners to genetics.

3. Cognitive styles, for example, field dependence/field independence in this study, may influence the learning of genetics. However, it is almost impossible to meet the needs of all the learning styles in a class of students. Nonetheless, the teacher should be aware that there will be variations in learning styles.

4. The nature of genetics knowledge certainly has the potential to cause the working memory to overload. When a new concept is introduced to the learners, the teacher should control the amount of useful information which the learner has to process and can also limit the extraneous distracting information in a learning situation, so that the working memory overload is minimised.

5. The teaching materials can be designed around applications and life experiences to create a more familiar context for the learning process (to concrete thinking). The learners can construct new concept based on the knowledge they already have. These should help learners developing positive attitudes, minimise working memory overloading, facilitate cognitive development toward formal thinking, and/or enable students to build on existing knowledge and assimilate and transfer new learning into the long-term memory.

6. Learning by means of groups with the materials can provide opportunities for learners to participate and learn through peer's language and group competition in order to increase motivation and improve understanding, which will lead to improve students' attitudes towards a subject.

7. The focus in teaching genetics should be more applications-led and should enable the learners to realise how genetics could be used positively in making decisions and choices.

9.6 Suggestions for further work

As in any other research, questions have arisen from this study and they can be point of departure for further research. There are some suggestions offered.

Firstly, the study has revealed that an understanding of certain key topics is extremely important for further study in genetics. For example, an understanding of mitosis and meiosis is very important for understanding Mendelism. Thus, more research is needed to explore the reasons for these relationships and, more importantly, how to improve the learning of these foundational concepts.

Secondly, as mentioned in the last section, the research can go further. The longer term effects of such teaching approaches needs explored as well as the need to check the findings by means of, perhaps, interviews.

Moreover, the new teaching material developed in genetics is an example, which relates to effective and efficient learning as well as the development of positive attitudes. The approach can be used as a means for applying to other cognate subjects. If there was a consistent development across many subject areas, following parallel approaches, then there would be the need for a major research project to measure the outcomes and to pinpoint further areas needing exploration and development.

Finally, it is hoped that this study will be able to contribute to the development of genetics as a school discipline so that students who complete courses will be equipped and motivated to make genetics learning more meaningful and practical to students, as well as being able to make future contributions based in genetics as well as many other career options.

References

Abell, S. K. (1994) What is science? Persevere elementary teachers' conception of the nature of science. *International Journal of Science Education*, 16(4), 475-485.

Aikenhead, G. S. (1986) The content of STS education. *STS Research Network Missive*, 2(3), 18-23.

Aikenhead, G. S. (1988) *Teaching Science through a Science-Technology-Society-Environment Approach: An Instruction Guide*, Regina, Saskatchewan: University of Regina.

Aikenhead, G. S. (1992) The integration of STS into science education. *Theory into Practice*, 31(1), 27-35.

Ajzen, I. and Fishbein, M. (1980) *Understanding Attitudes and Predicting Social Behaviour*, Englewood Cliffs, NJ: Prentice-Hall.

Alamolhodaei, A. (1996) *A Study of Learning Calculus in Higher Education and Students' Learning Styles*, Ph.D. Thesis, University of Glasgow.

Albaladejo, C. and Lucas, A. M. (1988) Pupils' meaning for 'mutation'. *Journal of Biology Education*, 22(3), 215-219.

Al-Enezi D. (2004) *Difficulties Associated with Teaching and Learning Mathematics: A Study of Psychological Factors Affecting Pupils' Performance*, M.Sc. Thesis, University of Glasgow.

Allport, G. W. (1935) Attitudes. In Murchison, C. (Ed) *A Handbook of Social Psychology*, Worcester, MA: Clark University Press.

Allport, G. W. (1954) *The Nature of Prejudice*, Reading, MA: Addison-Wesley.

Al-Naeme, F. F. (1988) *A Study of Some Psychological Factors Affecting Performance in Chemistry at Secondary and Tertiary Levels*, M.Sc. Thesis, University of Glasgow.

Al-Naeme, F. F. (1991) *The Influence of Various Learning Styles on Practical Problem-Solving in Chemistry in Scottish Secondary Schools*, Ph.D. Thesis, University of Glasgow.

Al-Qasmi, S. A. (2006) *Problem Solving in Biology at University Level*, Ph.D. Thesis, University of Glasgow.

Alparslan, C., Tekkaya, C. and Geban, O. (2003) Using the conceptual change instruction to improve learning. *Journal of Biology Education*, 37(3), 133-137.

Ambu-Saidi, A. K. A. (2000) *An Investigation into Fixed Response Questions in Science at Secondary and Tertiary Levels*, Ph.D. Thesis, University of Glasgow.

American Association for the Advancement of Science (AAAS) (1989) *Science for All Americans: A Project 2061 Report on Literacy Goals in Science, Mathematics, and Technology*, Washington, DC: AAAS.

American Association for the Advancement of Science (AAAS) (1990) *Science for All Americans*, New York: Oxford University Press.

American Association for the Advancement of Science (AAAS) (1993) *Benchmarks for Science Literacy*, New York: Oxford University Press.

Anderson, H. O., Harty, H. and Samuel, K. V. (1986) Nature of science, 1969 and 1984: Perspectives of pre-service secondary science teachers. *School Science and Mathematics*, 86(1), 43-50.

Anderson, P. W. (1993) Review of James Gleick's Genius. *Science*, 259, 22.

Armstrong, S. (2000) The Influence of individual cognitive style on performance in Management Education. *Educational Psychology*, 20(3), 323-340.

Arnaudin, M. W. and Mintzes J. J. (1985) Students' alternative conceptions of the human circulatory system: A cross age study. *Science Education*, 69, 721-733.

Ary, D., Jacobs, L. and Razavieh, A. (2001) *Introduction to Research in Education* (5th Ed), New York, USA: Holt, Rhinehart and Winston Inc.

Ashcraft, H. M. (1994) *Human Memory and Cognition*, New York, USA: Harper Collins College.

Ashcraft, H. M. (1998) *Fundamental of Cognition*, New York, U.S.: Addison-Wesley Educational Publishers, Inc.

Atkins, M., Beattie, J. and Dockrell, B. (1992) *Assessment Issues in Higher Education*, Newcastle School of Education, University of Newcastle.

Atkinson, R. L., Atkinson, R. C., Smith, E. E. and Bem, D. J. (1993) *Introduction to Psychology* (11th Ed), Fort Worth, USA: HBJ.

Atkinson, R. C. and Shiffrin, R. M. (1968) Human memory: A proposed system and its component processes. In Spence, K. and Spence, J. (Ed) *The Psychology of Learning and Motivation*, New York, USA: Academic Press, Vol. 2.

Atkinson, R. and Siffrin, R. (1971) The control of short-term memory. *Scientific American*, 225, 82-90.

Ausubel, D. P. (1963) *The Psychology of Meaningful Verbal Learning*, New York, USA: Grune and Startton.

Ausubel, D. P. (1968) *Educational Psychology: A Cognitive View*, New York, USA: Holt, Rinehart and Winston.

Ausubel, D. P. (1978) In defence of advance organizers: A reply to the critics. *Review of Educational Research*, 48, 251-257.

Ausubel, D. P. and Fitzgerald, D. (1962) Organizer, general background, and antecedent learning variables in sequential verbal learning. *Journal of Educational Psychology*, 53(6), 243-249.

Ausubel, D. P., Novak, J. and Hanesian, H. (1978) *Educational Psychology: A Cognitive View*, New York, USA: Holt, Rhinehart and Winston.

Ausubel, D. P. and Robinson, F. G. (1969) *School Learning: An Introduction to Educational Psychology*, New York, USA: Holt, Rinehart and Winston.

Baddeley, A. D. (1986) *A Working Memory*, London, UK: Oxford University.

Bahar, M. (1996) *A Diagnostic Study of Concept Difficulties in Secondary School Biology Courses*, M.Sc. Thesis, University of Glasgow.

Bahar, M. (1999) *Investigation of Biology Students' Cognitive Structure through Word Associated Tests, Mind Maps, and Structural Communication Grids*, Ph.D. Thesis, University of Glasgow.

Bahar, M. and Hansell, M. H. (2000) The relationship between some psychological factors and their effect on the performance of grid questions and word association tests. *Educational Psychology*, 20(3), 349-367.

Bahar, M., Johnstone, A. H. and Hansell, M. H. (1999a) Revisiting learning difficulties in biology. *Journal of Biology Education*, 33(2), 84-86.

Bahar, M., Johnstone, A. H. and Sutcliffe, R. (1999b) Investigation of student's cognitive structure in elementary genetics through word association test. *Journal of Biology Education*, 33(3), 134-141.

Bagozzi, R. P. (1978) The construct validity of the affective, behavioural, and cognitive components of attitude by analysis of covariance structures. *Multivariate Behavioural Research*, 13, 9-13.

Bagozzi, R. P. and Burnkrant, R. E. (1979) Attitude organisation and the attitude-behaviour relationship. *Journal of Personality and Social Psychology*, 37, 913-929.

Barber, P. (1988) *Applied Cognitive Psychology: An Information-Processing Framework*, New York, USA: Methuen and Co. Ltd.

Barclay, A. and Thumin, F. J. (1963) A modified semantic differential approach to attitudinal assessment. *Journal of Clinical Psychology*, 19:376-378.

Beard, R. (1969) *An Outline of Piaget's Developmental Psychology*, London: Routledge and Kegan Paul.

Bell, B. and Freyberg, P. P. (1985) Language in the science classroom. In Osborn, R. and Freyberg, P. P. *Learning in Science: The Implications of Children Science*, Heinemann, 29-40.

Bem, D. J. (1972) Self-perception theory. In L. Berkowitz (Ed) *Advances in Experimental Social Psychology*, San-Diego, CA: Academic Press, Vol. 6, 1-62.

Bentham, S. (2002) *Psychology and Education*, East Sussex, UK: Routledge Modular Psychology.

Berger, E. (1977) Field independence and short-term memory. *Abstract International Journal*, 38, 1870b.

Biggs, J. and Moore, P. (1993) *The Process of Learning* (3rd Ed), Toronto: Prentice Hall.

BioEd (2004) *Biology, Sustainable Development, Ethics and Citizenship Conference*, From IUBS-CBE Website: www.iubs.org/test/BioEd%202004/frBioEd2004.htm.

Bitro, M. R. (1995) *A Study about Attitudes towards Mathematics on Elementary and Secondary Schools*, Campinas, Barazil.

Bliss, J. (1995) Piaget and after: The case of learning science? *Studies in Science Education*, 25, 139-172.

Boersma, K. T. (1999) The Janus face of developmental research. Review of some designs of biology-didactical research. In Jong, O., Kortland, K., Waarlo, A. J. and Buddingh, J. (Ed) *Bridging the Gap between Theory and Practice: What Research Says to the Science Teacher*, Proceedings of the 1998 International Summer Symposium, Utrecht: CD-β Press, 31-46.

Botero, A. L. (1997) Scientific and technological literacy and economic development. *Innovation in Science and Technology Education*, 6, 201-214.

Bourne, L. F., Dominowski, R. L., Loftus, E. F. and Healy, A. F. (1986) *Cognitive Processes* (2nd Ed), Englewood, USA: Prentice-Hall Inc.

Bradley, J. and Hutchings, D. (1973) Concepts of science and scientists as factors affecting subject choice in secondary schools. *School Science Review*, 55, 8-15.

Brill, G., Falk, H. and Yarden, A. (2003) Teachers' journal club: Bridging between the dynamics of biological discoveries and biology teachers. *Journal of Biological Education*, 37(4), 168-170.

Brito, M. R. (1996) *A Study About Attitudes towards Mathematics on Elementary and Srcondary School*, Campinas, Barazil.

Brock, W. H. (1996) Science for all. *Studies in the History of Victorian Science and Education*, Aldershot: Variorum.

Bronsan, T. (1990) Categorizing macro and micro explanations of material change. In Lijnse, P. L., Licht, P., Vos, W. and Vaarlo, A. J. (Ed) *Relating Macroscopic Phenomena to Microscopic Particles*, Utrecht, Netherlands: CD-Press, 198-211.

Brown, C. R. (1990) Some misconceptions in meiosis shown by students responding to an advanced level practical examination question in biology. *Journal of Biology Education*, 24(3), 182-186.

Browning, M. E. and Lehman, J. D. (1988) Identification of student misconceptions in genetic problem solving via computer program. *Journal of Research in Science Teaching*, 25, 747-761.

Browning, M. E. and Lehman, J. D. (1991) Response to Dr. Smith's comments and criticisms concerning 'Identification of students misconceptions in genetics problem solving via computer programme'. *Journal of Research in Science Teaching*, 28(4), 385-386.

Bruner, J. (1996) *The Culture of Education*, USA: Harvard University Press.

Brunning, R. H., Schraw, G. J. and Ronning, R. R. (1995) *Cognitive Psychology and Instruction*, Englewood, USA: Prentice-Hall Inc.

Brunton, J. E. (1961) Deriving an attitude scale from semantic differential data. *Public Opinion Quarterly*, 25, 289-295.

Burkhardt, G., Monsour, M., Valdez, G., Gunn, C., Dawson, M., Lemke, C., Coughlin, E., Thadani, V. and Martin, C. (2000) *enGauge 21st Century Skills: Literacy in the Digital Age*, U.S.: The North Central Regional Educational Laboratory and the Metiri Group (NCREL).

Bybee, R. W. (1985) Science-Technology-Society. *1985 NSTA Yearbook*, Washington, DC: National Science Teachers Association.

Byrne, M. S. and Johnstone, A. H. (1987) Critical thinking and science education. *Studies in Higher Education*, 12(3), 325-339.

Byrne, M. S. and Johnstone, A. H. (1988) How to make science relevant. *School Science Review*, 70(251), 43-46.

Byrne, M. S., Johnstone, A. H. and Pope, A. (1994) Reasoning in science: A language problem revealed? *Science Education Notes*, 75(272), 103-107.

Cachapuz, A. and Maskill, R. (1987) Detecting changes with learning in the organization of knowledge: Use of word association tests to follow the learning of collision theory. *International Journal of Science Education*, 9(4), 491-504.

Cantril, H. (1934) The social psychology of everyday life. *Psychological Bulletin*, 31, 297-330.

Case, R. (1974) Structures and structures, some functional limitations on the course of cognitive growth. *Cognitive Psychology*, 6, 544 - 574.

Case, R. and Globerson, T. (1974) Field independence and central computing space. *Child Development*, 45, 772-778.

Cassels, J. R. T. and Johnstone, A. H. (1978) What's in a Word? *New Scientist*, 78, 1978, 432.

Cassels, J. R. T. and Johnstone, A. H. (1982) Meaning of words and the teaching of chemistry. *Education in Chemistry*, 20(1), 10-11.

Cassels, J. R. T and Johnstone, A. H. (1983) The effect of language on students' performance on multiple choice tests in chemistry. *Journal of Chemical Education*, 6(7), 613-615.

Cem, A., Ceren, T. and Omer, G. (2003) Using the conceptual change instruction to improve learning. *Journal of Biology Education*, 37(3), 133-137.

Chaiken, S. and Eagly, A. H. (1993) *The Psychology of Attitudes*, Orlando: Ted Buchholz.

Charlotte K. O. (1998) Learning Mendelian genetics through a simple coin toss game. *American Biology Teacher*, 60(8), 608-612.

Chassin, L., Presson, C. C. and Sherman, S. J. (1984) Cigarette smoking and adolescent psychosocial development. *Basic and Applied Social Psychology*, 5, 295-315.

Chattopadhyay, A. (2005) Understanding the genetic information in higher secondary students in Northeast India and the implications for genetics education. *Cell Biology Education*, 4, 97-104.

Cheek, D. W. (1992) Evaluating learning in STS education. *Theory into Practice*, 31(1), 64-72.

Chen, W. C. (2004) *An Analysis of Pupils' Difficulties in Physics in Relation to Working Memory Space*, M.Sc. Thesis, University of Glasgow.

Child, D. (1993) *Psychology and the Teacher* (5th Ed.), London: Cassell.

Cho, H., Kahle, J. B. and Nordland, F. H. (1985) An investigation of high school biology textbooks sources of misconceptions and difficulties in genetics and some suggestions for teaching genetics. *Science Education*, 69, 707-719.

Christou, K. (2001) *Difficulties in Solving Algebra Story Problems with Secondary School Pupils*, M.Sc. Thesis, University of Glasgow.

Cobern, C. C. (1996) Worldview theory and conceptual change in science education. *Science Education*, 80(5), 579-610.

Cohen, R. A. (1969) Conceptual styles, culture conflict and nonverbal tests of intelligence. *American Anthropologist*, 71, 828-856.

Collins, A. and Stewart, J. H. (1989) The knowledge structure of Mendelian genetics. *The American Biology Teacher*, 51, 143-149.

Colom, R., Flores-Mendoza, C. and Rebollo, I. (2003) Working memory and intelligence. *Personality and Individual Differences*, 34(1), 33-39.

Comstock, G., Chaffee, S., Katzman, N., McCombs, M. and Roberts, D. (1978) *Television and Human Behaviour*, New York: Columbia University Press.

Cook, S. W. and Selltiz, C. (1964) A multiple indicator a roach to attitude assessment, *Psychological Bulletin*, 62, 36-55.

Council of Ministers of Education of Canada (CMEC) (1997) *Common Framework of Science Learning Outcomes K to 12*, Toronto: Council of Ministers of Education, Canada.

Cowan, N. (2001) The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioural and Brain Sciences*, 24, 87-185.

Craik, F. and Lockhart, R. (1972) Levels of processing: A framework for memory research. *Journal of Verbal Thinking and Verbal Behaviour*, 11, 671-684.

Cross, K. L. (1976) *Accent on Learning*, New York, USA: Jossey Bass Publisher.

Danili, E. (2001) *New Teaching Materials for Secondary School Chemistry: A Study of Psychological Factors Affecting Pupil Performance*, M.Sc. Thesis, University of Glasgow.

Danili, E. (2004) *A Study of Assessment Formats and Cognitive Styles Related to School Chemistry*, Ph.D. Thesis, University of Glasgow.

Davis, J. K. (1991). Educational implications of field dependence-independence. In Wapner, S. and Demick, J. (Ed) *Field Dependence-Independence: Cognitive Style Across the Lifespan*, Hillsdale, NJ: Lawrence Erlbaum Associates, 149-175.

Deadman, J. A. and Kelly, P. P. J. (1978) What do secondary school boys understand about evolution and heredity before they are taught the topics? *Journal of Biology Education*, 12(1), 7-15.

DeBoer, G. E. (2000) Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, 37, 582-601.

Deese, J. (1965) *The Structure of Association in Language and Thought*, Baltimore: The Johns Hopkins University Press.

Devin, T. and Williams, H. (1992) Hand up those who were happy at school. *New Scientsit*, 26 September.

Driver, R. and Bell, B. (1986) Students' thinking and the learning of science: A constructivist view. *The School Science Review*, 67(240), 443-456.

Driver, R., Guesne, E. and Tiberghien, A. (1985) *Children Ideas in Science*, Milton Keynes: Open University Press.

Driver, R., Newton, P. and Osborne, J. (2000) Establishing the norms of scientific argumentation in classrooms. *Science Education*, 84, 287-312.

Driver, R. and Oldham, V. (1986) A constructivist approach to curriculum development in science. *Studies in Science Education*, 13, 105-122.

Dubois, T. E. and Cohen, W. (1970) Relationship between measures of psychological differentiation and intellectual ability. *Perceptual and Motor Skills*, 31, 411-416.

Duncan, K. D. (1974) Analytical techniques in training design. In Edwards, E. and Lees, F. P. (Ed) *The Human Operator in Process Control*, London, UK: Taylor and Francis, 283-319.

Durkhein, E. (1994) *Pragmatism and the Question of Truth*. From http://home.mira.net/~gattcam/phil/durkheim.htm.

Dyer, J. E. (1995) Attitudes of University of Illinois College of Agricultural freshmen toward agriculture. *Journal of Agricultural Education*, 37(3), 43-51.

Egan, K. (1972) Structural communication - A new contribution to pedagogy. *Programmed Learning and Educational Technology*, 9(2), 63-78.

Eggen, P. (1999) *Educational Psychology*, New Jersey, USA: Merrill-Prentice Hall.

Eijkelhof, H. M. C. and Kortland, K. (1988) Broadening the aims of physics education. In Fensham, P. J. (Ed) *Development and Dilemmas in Science Education*, New York: Falmer Press.

El-Banna, H. (1987) *The Development of a Predictive Theory of Science Education based upon Information Processing Theory*, Ph.D. Thesis, University of Glasgow.

Elkana, Y. and Mendelsohn, E. (1981) Science and cultures, anthropological and historical studies of the sciences. *Sociology of the Sciences Yearbook*, Boston: Dordrecht, Vol. 5.

Entwistle, N. J. (1981) *Styles of Teaching and Learning: An Integrated Outline of Educational Psychology for Students, Teachers and Lectures*, Chichester: Wiley.

Falayajo, W. and Akindehin, F. (1986) Scientific literacy as a goal. *Nigerian Journal of Curriculum Studies*, 4(2), 73-81.

Fazio, R. H. (1988) On the power and functionality of attitudes: The role of attitude accessibility. In Pratkanis, A. R., Breckler, S. J. and Greenwald, A. G. (Ed) *Attitude Structure and Function*, Hillsdale, NJ: Erbaum.

Fensham, P. J. (1988) Approaches to the teaching of STS in science education. *International Journal of Science Education*, 10(4), 346-356.

Fensham, P. J. (1992) Science and technology. In Jackson, P. W. (Ed) *Handbook of Research on Curriculum*, New York: Macmillan.

Finely, F., Steward, L. and Yaroch, L. (1982) Teachers' perception of important and difficult science content. *Science Education*, 66(4), 531-538.

Fishbein, M. and Ajzen, I. (1974) Attitudes towards objects as predictors of single and multiple behavioural criteria. *Psychological Review*, 81, 59-74.

Fishbein, M. and Ajzen, I. (1975) *Belief, Attitude, Intention, and Behaviour: An Introduction to Theory and Research*, Reading, MA: Addison-Wesley.

Fisher K. M. (1985) A misconception in biology: Amino acids and translation. *Journal of Research in Science Teaching*, 22, 53-62.

Flavell, J. H. (1963) *The Development Psychology of Jean Piaget*, New York, USA: Van Nostrad.

Forns-Santacana, M., Amador-Campos, J. A. and Roig-Lopez, F. (1993) Differences in field dependence-independence cognitive styles as a function of socio-economic status, sex and cognitive competence. *Psychology in the Schools*, 30, 176-186.

Frank, B. M. (1984) Effect of field independence-dependence and study technique on learning from lecture. *American Educational Research Journal*, 21, 669-678.

Freyberg, P. P. (1985) Children science. In Osborne, R. and Freyberg, P. P. *Learning in Science: The Implications of Children Science*, Heinemann, 5-14.

Gagne, R. M. and Medsker, K. L. (1996) *The Conditions of Learning Training Applications*, Florida, USA: Harcourt Brace and Company.

Gardner, P. L. (1975) Attitude to science: A review. *Studies in Science Education*, 2, 1-41.

Garger, S. and Guild, P. (1987) Learning styles: The crucial differences. *Curriculum Review*, 9(12), 13-17.

Geary, D. C. and Widaman, K. F. (1992) Numerical cognition: On the convergence of componential and psychometric models. *Intelligence*, 16, 47-80.

Gerard, H. B. and Orive, R. (1987) The dynamics of opinion formation. In Berkowitz L. (Ed) *Advances in Experimental Social Psychology*, San Diego: Academic Press.

Germann, P. J. (1988) Development of the attitude towards science in school assessment and its use to investigate the relationship between science achievement and attitude towards science in school. *Journal of Research in Science Teaching*, 25(8), 689-703.

Ghani, S. A. (2004) *Attitude, Performance and Psychological Characteristics of Student Teachers Learning Introductory Statistics*, Ph.D. Thesis, University of Glasgow.

Goldstein, K. M. and Blackman, S. (1978) *Cognitive Style: Five Approaches and Relevant Research*, New York: Wiley.

Good, T. L. and Brophy, J. E. (1990) *Educational Psychology: A Realistic Approach*, New York, USA: Longman.

Goodenough, D. R. (1976) The role of individual differences in field dependence as a factor in learning and memory. *Psychological Bulletin*, 83, 675-694.

Gott, R. and Johnson, P. (1999) Science in schools: Time to pause for taught. *School Science Review*, 81(295), 21-28.

Gray, C. (1997) *A Study of Factors Affecting a Curriculum Innovation in University*, Ph.D. Thesis, University of Glasgow.

Green, K. (1985) *Cognitive Style: A Review of the Literature*, Chicago, USA: JOCRF.

Griffin, R. and Franklin, G. (1996) Can college academic performance be predicted using a measure of cognitive style? *Journal of Educational Technology Systems*, 24(4), 375-379.

Hackling, M. and Treagust, D. (1984) Research data necessary for meaningful review of grade ten high school genetics curricula. *Journal of Research in Science Teaching*, 21, 197-209.

Hallden, O. (1988) The evolution of the species: Pupil perspectives and school perspectives. *International Journal of Science Education*, 10, 541-552.

Halliday, M. S. and Hitch, G. J. (1988) Developmental applications of working memory? In Claxton, G. (Ed) *Growth Points in Cognition*, London, UK: Routledge.

Hamachek, D. (1995) *Psychology in Teaching, Learning and Growth*, New York, USA: Allyn and Bacon.

Hanrahan, M. (1999) Rethinking science literacy: Enhancing communication and participation in school science through affirmational dialogue journal writing. *Journal of Research in Science Teaching*, 36, 699-717.

Hart, E. P. (1989) Toward renewal of science education: A case study of curriculum policy development. *Science Education*, 73(5), 607-634.

Hartley, J. (1998) *Learning and Studying*, *A Research Perspective*, London, UK: Routledge.

Hassan, A. K. (2003) *An Exploration of Underlying Concepts Held by Prospective Students of Organic Chemistry*, M.Sc. Thesis, University of Glasgow.

Hassan, A. K., Hill, R. A. and Reid, N. (2004) Ideas underpinning success in an introductory course in organic chemistry. *University Chemistry Education*, 8, 40-51.

Hassard, J. (2000) *Backup of Meaningful Learning Model.* From http://scied.gsu.edu/Hassard/mos/mos.html.

Hayes, J. and Allinson, C. W. (1988) Cultural differences in the learning styles of managers. *Management International Review*, 28, 75-80.

Henerson, M. E., Morris, L. L. and Fitz-Gibbon, C. T. (1978) *How to Measure Attitudes*, London: Beverly Hills, Sage Publications Ltd.

Herron, J. D. (1996) *The Chemistry Classroom: Formulas for Successful Teaching*, Washington: American Chemical Society.

Hindal, H. S. (2007) *Cognitive Characteristics of Students in Middle Schools in State of Kuwait, with Emphasis on High Achievement*, Ph.D. Thesis, University of Glasgow.

Hodson, D. (2003) Time for action: Science education for an alternative future. *International Journal of Science Education*, 25, 645-670.

Hoffman, L. W. (1977) Changes in family roles, socialisation and sex differences. *American Psychologist*, 32, 644-657.

Hofstein, A., Aikenhead, G., and Riquarts, K. (1988) Discussions over STS at the fourth IOSTE symposium. *International Journal of Science Education*, 10(4), 357-366.

Holbrook, J. B. (1992) Teaching science the STS way. In Yager, R. E. (Ed) *The Status of STS: Reform Efforts Around the World*, ICASE 1992 Yearbook, Knapp Hill, South Harting, Petersfield, UK: International Council of Associations for Science Education.

Holzman, P. S. and Klein, G. S. (1954) Cognitive-system principles of levelling and sharpening: Individual differences in visual time-error assimilation effect. *Journal of Psychology*, 37, 105-122.

Hudson, L. (1966) *Contrary Imaginations*, London: Methuen.

Hulme, C., Roodenrys, S., Brown, G. and Mercer, R. (1995) The role of long-term memory mechanisms in memory span. *British Journal of Psychology*, 86, 527-536.

Hussein, F. K. A. (2006) *Exploring Attitudes and Difficulties in School Chemistry in the Emirates*. Ph.D. Thesis, University of Glasgow.

Hurd, P. D. (1998) Scientific literacy: New minds for a changing world. *Science Education*, 82, 407-416.

Hutchings, D. W. (1967) Girls' attitude to science. *New Society*, 6 November.

Inhelder, B. and Paiget, J. (1958) *The Growth of Logical Thinking from Childhood to Adolescence*, New York: Basic Book.

Jamieson, D. W. and Zanna, M. P. (1988) Need for structure in attitude formation and expression. In Pratkanis, A. R., Breckler, S. J. and Greenwald, A G. (Ed) *Attitude Structure and Function*, Hillsdale, NJ: Erlbaum.

Jarman, R. and McAleese, L. (1996) Physics for the stargazer: Pupils' attitudes to astronomy in the Northern Ireland Science Curriculum. *Physics Education*, 31, 223-226.

Johnson, P. E. (1967) Some psychological aspects of subject-matter structure. *Journal of Educational Psychology*, 58, 75-83.

Johnstone, A. H. (1974) Evalution of chemistry syllabuses in Scotland. *Studies in Science Education*, 1, 21.

Johnstone, A. H. (1984) New stars for the teacher to steer by? *Journal of Chemical Education*, 61(10), 847- 849.

Johnstone, A. H. (1987) Cognitive development and the teaching and learning of chemistry. *V.C.V. Tijidingen*, Nov., 45-58.

Johnstone, A. H. (1988) Methods of assessment using grids. *Lab Talk*, 10, 4-6.

Johnstone, A. H. (1991) Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, 7, 75-83.

Johnstone, A. H. (1993) The development of chemistry teaching: a changing response to changing demand. *Journal of Chemical Education*, 70(9), 701-705.

Johnstone, A. H. (1997) Using a model of learning of give direction to developments. In Thompson, D. L. *Science Education in the 21st Century*, Aldershat: Arena.

Johnstone, A. H. (1999) The nature of Chemistry. *Education in Chemistry*, 36(2), 45-48.

Johnstone, A. H. (2003) *Effective Practice in Objective Assessment*, LTSN Physical Sciences Centre.

Johnstone, A. H. and Al-Naeme, F. (1991) Room for scientific thought? *International Journal of Science Education*, 13, 187-192.

Johnstone, A. H. and Ambusaidi, A. (2000) Fixed response: What are we testing? *Chemistry Education Research and Practice in Europe*, 1(3), 323-328.

Johnstone, A. H. and Ambusaidi, A. (2001) Fixed-response questions with a difference. *Chemistry Education: Research and Practice in Europe*, 2(3), 313-327.

Johnstone, A. H., Bahar, M. and Hansell, M. H. (2000) Structural communication grids: A valuable assessment and diagnostic tool for science teachers. *Journal of Biology Education*, 34(2), 87-89.

Johnstone, A. H., and El-Banna, H. (1986) Capacities, demands and processes: a predictive model for science education. *Education in Chemistry*, 23(3), 80-84.

Johnstone, A. H., and El-Banna, H. (1989) Understanding learning difficulties - A predictive research model. *Studies in Higher Education*, 14(2), 159-168.

Johnstone, A. H., Hogg, W. R. and Ziane, M. (1993) A working memory model applied to physics problem solving. *International Journal of Science Education*, 15(6), 663-672.

Johnstone, A. H. and Mahmound N. A. (1980) Isolating topic of high perceived difficulty in school biology. *Journal of Biology Education*, 14(2), 163-166.

Johnstone, A. H. and Mahmound N. A. (1981) Pupils response to a model for water transport. *Journal of Biology Education*, 15(3), 203-208.

Johnstone, A. H. and Moynihan, A. (1985) The relationship between performance in word association tests and achievement in chemistry. *The European Journal of Science Education*, 7(1), 57-66.

Johnstone, A. H. and Mughol, A. N. (1976) A study of the concepts of physics at secondary school level. *Physics Education*, 11, 466.

Johnstone, A. H. and Mughol, A. N. (1979) Testing for understanding. *School Science Review*, 61, 174-185.

Johnstone, A. H. and Reid, N. (1981) Towards a model for attitude change. *European Journal of Science Education*, 3(2), 205-212.

Johnstone, A. H. and Selepeng, D. (2001) A language problem revisited. *CERAPIE*, 2(1), 19-29.

Johnstone, A. H., and Wham, A. J. B. (1982) Demands of practical work. *Education in Chemistry*, 19(3), 71-73.

Jung, E. S. (2005) *Attitudes and Learning Difficulties in Middle School Science in South Korea*, M.Sc. Thesis, University of Glasgow.

Kagan, J. (1965) Individual differences in the resolution of response uncertainty. *Journal of Personality and Social Psychology*, 2, 154-160.

Kahtz, A. W. and Kling, G. (1999) Field dependent and field independent conceptualisations of various instructional methods: A qualitative analysis. *Educational Psychology*, 19, 413-429.

Kapteijn, M. (1990) The functions of organizational levels in biology for describing and planning biology education. In Lijnse, P. L., Licht, P., Vos, W. and Vaarlo, A. J. (Ed) *Relating Macroscopic Phenomena to Microscopic Particles*, Utrecht, Netherlands: CD-Press, 139-150.

Karbo, D. B., Hobbs, E. D. and Erikson, G. L. (1980) Children's beliefs about inheritance characteristics. *Journal of Biology Education*, 14(2), 137-146.

Kaufman, G. (1979) The explorer and the assimilator: A cognitive style distinction and its potential implications for innovative problem solving. *Scandinavian Journal of Educational Research*, 23, 101-108.

Kellong, R. (1995) *Cognitive Psychology*, London, UK: Sage.

Kempa, R. and Nicholls, C. (1983) Problem-solving ability and cognitive structure - An exploratory investigation. *European Journal of Science Education*, 5, 171-184.

Kesner, M., Hofstein, A. and Ben-Zvi, R. (1997) Student and teacher perceptions of industrial chemistry case studies. *International Journal of Science Education*, 19, 725-738.

Khan, S. B. and Weiss, J. (1973) *Second Handbook of Research in Teaching* (Ed), Travers, Chicago: Rand McNally, Chapter 24.

Kinder, D. R. and Sears, D. O. (1985) Public opinion and political action. In Lindzey, G. and Aronson, E. (Ed) *The Handbook of Social Psychology*, New York: Random House.

Kindfield, A. C. H. (1991) Confusing chromosome number and structure: A common student error. *Journal of Biology Education*, 25(3), 193-200.

Kindfield, A. C. H. (1994) Understanding a basic biological process: Expert and novice models of meiosis. *Science Education*, 78, 255-283.

King, K. (1989) Primary schooling and developmental knowledge in Africa. *Studies in Science Education*, 17, 29-56.

Kinnear, J. (1983) Identification of misconceptions in genetics and the use of computer simulations in their correction. In Helm, H. and Novak, J. D. (Ed) *Proceedings of the International Seminar on Misconceptions in Science and Mathematics*, Ithaca, NY: Cornell University, 101-110.

Kirton, M. J. (1976) Adaptors and innovators: A description and measure. *Journal of Applied Psychology*, 61, 622-629.

Klatzky, R. L. (1975) *Human Memory: Structures and Processes*, New York, USA: W. H. Freman and Company.

Knippels, M. C. P. J., Waarlo, A. J. and Boersma, K. T. (2000) Biology teachers' perceptions of learning problems in Mendelian genetics. In Anderson, B., Harms, U., Hellden, G. and Sjobeck, M. L. (Ed) *Research in Didaktik of Biology.* Proceedings of the Second conference of European Researchers in Didaktik of Biology (ERIDOB), Goteborg 1998, Goteborgs Universitet: NA-Spektrum, 269-274.

Knippels, M. C. P. J., Waarlo, A. J. and Boersma, K. T. (2005) Design criteria for learning and teaching genetics. *Journal of Biology Education*, 39(3), 108-112.

Kogan, N. (1976) *Cognitive Styles in Infancy and Early Childhood*, New Jersey: Lawrence Erlbaum Associates, Inc.

Kolsto, S. D. (2001) Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socio-scientific issues. *Science Education*, 85, 291-310.

Korchin, S. J. (1986) Field dependence, personality theory, and clinical research. In Bertini, M., Pizzamiglio, L. and Wapner, S. (Ed) *Field Dependence in Psychological Theory, Research, and Application*, New York: Cambridge University Press.

Korpan, C. A., Bisanz, G. L., Bisanz, J., and Henderson, J. M. (1997) Assessing literacy in science: Evaluation of scientific news briefs. *Science Education*, 81, 515-532.

Krogh, L. B. and Thomson, P. V. (2005) Studying students' attitudes towards science from a cultural perspective but with quantitative methodology: Border crossing into the physics classroom. *International Journal of Science Education*, 27(3), 281-302.

Kyle, W. C., Jr. (1995a) Scientific literacy: How many lost generations can we afford? *Journal of Research in Science Teaching*, 32, 895-896.

Kyle, W. C., Jr. (1995b) Scientific literacy: Where do we go from here? *Journal of Research in Science Teaching*, 32, 1007-1009.

Langford, P. (1989) *Educational Psychology: An Australian Perspective*, Sydney: Longman Cheshire

Larochelle, M., Madine, B. and Garrison, J. (1998) *Constructivism and Education*, New York, USA: Cambridge University Press.

Lawson, A. E. and Renner, J. W. (1975) Relationships of science subject matter and developmental levels of learners. *Journal of Research in Science Teaching*, 12, 347-358.

Lederman, N. G. (1986) Students' and teachers' understanding of the nature of science: A reassessment. *School Science and Mathematics*, 86(2), 91-99.

Lee, O. (1997) Scientific literacy for all: What is it, and how can we achieve it? *Journal of Research in Science Teaching*, 34, 219-222.

Lee, O. (1999) Science knowledge, world views, and information sources in social and cultural contexts: Making sense after natural disaster. *American Educational Research Journal*, 36(2), 187-219.

Leonard, D. and Straus, S. (1997) Putting your company's whole brain to work. *Harvard Business Review*, 75, 111-121.

Lewis, J. and Wood-Robinson, C. (2000) Genes, chromosomes, cell division and inheritance - Do students see any relationship? *International Journal of Science Education*, 22(2), 177-195.

Lewis, J., Leach, J., and Wood-Robinson, C. (2000a) Chromosomes: The missing link - Young people's understanding of mitosis, meiosis, and fertilization. *Journal of Biology Education*, 34(4), 189-199.

Lewis, J., Leach, J., and Wood-Robinson, C. (2000b) All in the genes? - Young people's understanding of the nature of genes. *Journal of Biology Education*, 34(2), 74-79.

Lewis, J., Leach, J., and Wood-Robinson, C. (2000c) What's in a cell? - Young people's understanding of the genetic relationship between cells, within an individual. *Journal of Biology Education*, 34(3), 129-132.

Lewis, J. and Kattmann, U. (2004) Traits, genes, particles and information: Revisiting students' understanding of genetics. *International Journal of Science Education*, 26(2), 195-206.

Lijnse, P. L. (1990) Macro-Micro: What to discuss? In Lijnse, P. L., Licht, P., Vos, W. and Vaarlo, A. J. (Ed) *Relating Macroscopic Phenomena to Microscopic Particles*, Utrecht, Netherlands: CD-Press, 6-11.

Likert, R. (1932) A technique for the measurement of attitudes. *Archives of Psychology*, 140, 5-53.

Liu, M and Reed, W. M. (1994) The relationship between the learning strategies and learning styles in a hypermedia environment. *Computers in Human Behaviour*, 10(4), 419-434.

Lock, R., Miles, C. and Hughes, S. (1995) The influence of teaching on knowledge and attitudes in biotechnology and genetic engineering contexts: Implications for teaching controversial issues and the public understanding of science. *School Science Review*, 76(276), 47-59.

Longden, B. (1982) Genetics - Are there inherent learning difficulties? *Journal of Biology Education*, 16(2), 135-140.

MacDonald, E. R. (1984) The relationship of student and faculty field-dependence independence congruence to student academic achievement. *Educational and Psychological Measurement*, 44(3), 725-731.

MacGuire, P. R. P. and Johnstone, A. H. (1987) Techniques for investigating the understanding of concepts in science. *International Journal of Science Education*, 9(5), 565-577.

Mason, E. J. and Bramble, W. J. (1989) *Understanding and Conducting Research: Applications in Education and the Behavioural Sciences* (Ed), Singapore: McGraw-Hill, Inc.

Marbach-Ad, G (2001) Attempting to break the code in students' comprehension of genetic concepts. *Journal of Biology Education*, 35(4), 183-189.

Marbach-Ad, G and Stavy, R. (2000) Student's cellular and molecular explanation of genetic phenomena. *Journal of Biology Education*, 34(4), 200-205.

Martins, I. and Ogborn, J. (1997) Metaphorical reasoning about genetics. *International Journal of Science Education*, 19, 47-63.

Mayer, R. (2003) *Learning and Instruction*, New Jersey: Pearson Education, Inc.

Mayer, V. J. (1997) Global science literacy: An earth system view. *Journal of Research in Science Teaching*, 34, 101-105.

Mbajiorgu, N. M. and Ali, A. (2003) Relationship between STS approach, scientific literacy, and achievement in biology. *International Journal of Science Education*, 87, 31-39.

McGuire, W. J. (1985) Attitudes and attitude change. In Lindzey, G. and Aronson, E. (Ed) *Handbook of Social Psychology*, New York: Random House.

Meichtry, Y. J. (1993) The impact of science curricula on student views about the nature of science. *Journal of Research in Science Teaching*, 3015, 429-443.

Mendelsohn, E. (1976) Values and science: A critical reassessment. *Science Teacher*, 43(1), 20-23.

Messick, S (1976) Personality consistencies in cognition and creativity. In Messick, S. and Associates (Ed) *Individuality and Learning*, San Francisco, USA: Joey-Bass.

Messick, S. (1984). The psychology of educational measurement. *Journal of Educational Measurement*, 21, 215-238.

Messick, S. (1993) *The Matter of Style: Manifestations of Personality in Cognition, Learning and Teaching*, Princeton, NJ: Educational Testing Service.

Miller, A. (1987) Cognitive styles: An integrated model. *Educational Psychology*, 7, 251-268.

Miller, G. D. (1956) The magical number seven plus or minus two: some limits on our capacity for processing information. *Psychological Review*, 63, 81-97.

Miller, J. D. (1983) Scientific literacy: A conceptual and empirical review. *Daedalus*, 112(2), 29-48.

Miller, P. H. (1993) *Theories of Developmental Psychology*, New York, USA: W. H. Freeman and Company.

Millar, R. (1996) Towards a science curriculum for public understanding. *SSR*, 77(280), 7-18.

Miller, R. and Osborne, J. (1998) *Beyond 2000: Science Education for the Future (the Report of a Seminar Series Funded by the Nuffield Foundation)* (Ed), London: King's College London.

Ministry of Education of Taiwan (2007) *2007 Education in Taiwan*, Taipei, Taiwan (R.O.C.): Ministry of Education.

Moll, M. B. and Allen, R. D. (1987) Student difficulties with Mendelian genetics problem. *The American Biology Teacher*, 49(4), 229-233.

Musser, T. (1998) *Individual Differences: How Field Dependence-Independence Affect Learners*. From http://www.personal.psu.edu/staff/t/x/txm4/paper1.html

Nagy, P. (1983) Assessing cognitive structure: A response to Stewart. *Science Education*, 67(1), 25-36.

National Academy of Sciences in USA (1995) *National Science Education Standards in USA*. From http://www.nap.edu/readingroom/books/nses.

National Science Board of USA (2002) Science and technology: Public attitudes and public understanding. *Science and Engineering Indicators - 2002*, Washington, DC, U.S.: Government Printing Office.

National Science Teachers Association in USA (NSTA) (1982) *Science-Technology-Society: Science Education for the 1980s (NSTA Position Statement)*, Washington, DC: Author.

National Research Council in USA (NRC) (1996) *National Science Education Standards*, Washington, DC: National Academy of Sciences.

Nickols, S. A. and Shaw, M. E. (1964) Saliency and two measures of attitude. *Psychological Reports*, 14:273-274.

Norman, O. (1998) Marginalised discourses and scientific literacy. *Journal of Research in Science Teaching*, 35, 365-374.

Norris, S. P. and Phillips, L. M. (2003) How literacy in its fundamental sense is central to scientific literacy. *International Journal of Science Education*, 87, 224-240.

Oberauer, K., Heiz-Martin, S. Wilhelm O. and Wittman, W. (2003) The multiple faces of working memory: Storage, processing, supervision and coordination. *Intelligence*, 31(2), 167-193.

Osborne, J., Simon, S. and Collins, S. (2003) Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, 25(9), 1049-1079.

Oskamp, S. (1991) *Attitudes and Opinions* (Ed), Prentice-Hall, Inc.

Opdenacker, C., Fierens, H., Van Brabant, H., Sprut, J. and Johnstone, A. H. (1990) Academic performance in solving chemistry problems related to student working memory capacity. *International Journal of Science Education*, 12(2), 177-185.

Oppenheim, A. N. (1992) *Questionnaire Design, Interviewing and Attitude Measurement*, London and New York: Pinter Publishers.

Osgood, C. E., Suci, G. J. and Tannembaum, P. H. (1957) *The Measurement of Meaning*, Urbana: University of Illinois Press.

Osgood, C. E., Suci, G. J. and Tannembaum, P. H. (1969) *Attitude Measurement*, Rand McNally: Chicago.

Pascual-Leone, J. (1970) A mathematical model for the transition rule in Piaget's development stages. *Act Psychological*, 32, 301-345.

Pascual-Leone, J. (1974) *Manual for Figural Intersection Test*, Canada: York University Press.

Pashley, M. A. (1994a) A level students: Their problems with gene and allele. *Journal of Biology Education*, 28(2), 120-126.

Pashley, M. A. (1994b) A chromosome model. *Journal of Biology Education*, 28(3), 157-161.

Pearson, J. T. and Hughes, W. J. (1988a) Problems with the use of terminology in genetics: 1 - A literature review and classification scheme. *Journal of Biology Education*, 22(3), 178-182.

Pearson, J. T. and Hughes, W. J. (1988b) Problems with the use of terminology in genetics: 2 - Some examples from published materials and suggestions for rectifying problems. *Journal of Biology Education*, 22(4), 267-274.

Pederson, J. E. (1992) The jurisprudential model of study for STS issues. In Yager, R. E. (Ed) *The Status of STS: Reform Efforts Around the World*, ICASE 1992 Yearbook, Knapp Hill, South Harting, Petersfield, UK: International Council of Associations for Science Education.

Pell, T. and Jarvis, T. (2001) Developing attitude to science scales for use with children of ages from five to eleven years. *International Journal of Science Education*, 23(8), 847-862.

Pell, T. and Jarvis, T. (2004) Primary teachers changing attitudes and cognition during a two-year science in-service programme and their effect on pupils. *International Journal of Science Education*, 26(14), 1787-1811.

Phillips, D. C. (1998) *Perspectives on Learning*, New York, USA: Teachers College Press.

Piaget, J. (1961) The genetic approach to psychology of thought. *Journal of educational psychology*, 52(6), 275-281.

Piaget, J. (1962) *Play, Dreams and Imitation in Childhood*, New York, USA: Norton.

Piaget, J. and Inhelder, B. (1969) *The Psychology of The Child*, New York, USA: H. Weaver and Trans.

Pizzamiglio, L. (1974) Handedness, preference and field dependence. *Perceptual and Motor Skills*, 38, 700-702.

Pritchard, A. J. (1990) Biology education and particulate theory: too much chemicals! In Lijnse, P. L., Licht, P., Vos, W. and Vaarlo, A. J. (Ed) *Relating Macroscopic Phenomena to Microscopic Particles*, Utrecht, Netherlands: CD-Press, 131-138.

Pulaski, M. A. S. (1980) *Understanding Piaget* (Ed), New York, USA: Harper and Row.

Ramorogo, G. and Wood-Robinson, C. (1995) Botswana children's understanding of biological inheritance. *Journal of Biology Education*, 29(1), 60-72.

Ramsden, J. M. (1998) Mission impossible? Can anything be done about attitudes to science. *International journal of Science Education*, 20(2), 125-137.

Ravetz, J. R. (1997) Simple scientific truths and uncertain policy realities - Implications for science education. In Donnelly, J. (Ed) *Studies in Science and Maths Education*, Leeds: University of Leeds, 5-18.

Reid, N. (1978) *Attitude Development through a Science Curriculum*, Ph.D. Thesis, University of Glasgow.

Reid, N. (1999) Towards an applications led curriculum? *Staff and Educational Development International*, 3(1), 71-84.

Reid, N. (2000) The presentation of chemistry logically driven or application-led? *Chemistry Education: Research and Practice in Europe*, 1(3), 381-392.

Reid, N. (2003) *Getting Started in Pedagogical Research in the Physical Sciences*, Hull, UK: LTSN Physical Sciences Centre.

Reid, N. (2004) *Getting Started in Pedagogical Research in the Physical Sciences*, LTSN Physical Sciences Practice Guide: Hull, LTSN.

Reid, N. (2006) Thoughts on attitude measurement. *Research in Science and Technological Education*, 24(1), 3-27.

Reid, N. and Serumola, L. (2006) Scientific enquiry. The nature and place of experimentation: A review. *Journal of Science Education*, 4, 5-9.

Reid, N. and Skryabina, E. (2002a) Attitudes towards physics. *Research in Science and Technological Education*, 20(1), 67-81.

Reid, N. and Skryabina, E. (2002b) Gender and physics. *International Journal of Science Education*, 25(4), 509-536.

Reid, N and Yang, M. J. (2002) The solving of problems in chemistry: the more open-ended problems. *Research in Science and Technological Education*, 20, 83-98.

Reid, P. A. (2002) *Problem Solving by Primary School Children with Particular Reference to Dyslexics*, M.Sc. Thesis, University of Glasgow.

Reiff, J. (1996) At risk middle level students or field dependent learners. *Clearing House*, 69(4), 231-234.

Reiss, M. J. (1998) The future of life science education. *School Science Review*, 79(289), 19-24.

Renshon, S. A. (1977) *Handbook of Political Socialisation: Theory and Research* (Ed), New York: Free Press.

Rhine, R. J. (1958) A concept formation approach to attitude acquisition. *Psychology Review*, 65, 362-370.

Riding, R. and Cheema, I. (1991) Cognitive styles - An overview and integration. *Educational Psychology*, 11, 193-215.

Riding, R. and Rayner, S. (1999) *Cognitive Styles and Learning Strategies: Understanding Style Differences in Learning and Behaviour*, London, UK: David Fulton Publishers.

Roberts, D. A. (1988) What counts as science education? In Fensham, P. J. (Ed) *Development and Dilemmas in Science Education*, New York: Flamer Press.

Roberts, D. F. and Maccoby, N. (1985) Effects of mass communication. In Lindzey, G. and Aronson, E. (Ed) *The Handbook of Social Psychology*, New York: Random House.

Rodefeld, R. D. (1967) *The Generalized Attitude of Members Toward their General Farm Organization*, M.S. Thesis, University of Wisconsin.

Rokeach, M. (1968) *Beliefs, Attitudes, and Values: A Theory of Organisation and Change*, San Francisco: Jossey-Bass.

Rollock, D. (1992) Field-dependence/independence and learning condition - An exploratory study of styles vs. ability. *Perceptual and Motor Skills*, 74(3), 807-818.

Romberg, T. and Carpenter, T. (1986) Research on teaching and learning mathematics: Two disciplines in scientific inquiry. In Wittrock, M. (Ed) *Handbook of Research on Teaching*, New York, USA: Macmillan.

Rowe, M. B. (1983) Science education: A framework for decision makers. *Journal of the American Academy of Arts and Sciences*, 112(2), 123-142.

Rubba, P. A. and Anderson, A. O. (1978) Development of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. *Science Education*, 62(4), 449-458.

Ruble, D. N. and Nakamura, C. Y. (1972) Task orientation versus social orientation in young children and their attention to relevant social cues. *Child Development*, 6, 471-80.

Ryman, D. (1974) Children understanding of the classification of living organisms. *Journal of Biology Education*, 8(3), 140-144.

Sadler, T. D., Amirshokoohi, A., Kazempour, M. and Allspaw, K. M. (2006) Socioscience and ethics in science classrooms: Teacher perspectives and strategies. *Journal of Research in Science Teaching*, 43(4), 353-376.

Sanford, A. J. (1985) *Cognition and Cognitive Psychology*, London, UK: Weidenfeld and Nicolson.

Saracko, O. N. (1997) *Teachers' and Students' Cognitive Style in Early Childhood Education*, Westport: Bergin and Garvey.

Schaefer, G. (1979) Concept formation in biology: The concept 'growth'. *European Journal of Science Education*, 1(1), 87-101.

Science and Technology Committee Report (2002) *Science Education from 14-19 Third Report of Session* (England and Wales), London: The Stationary Office Limited.

Scottish Exam Board (1997) *Higher Grade Biology Examination Papers*, Glasgow: Gibson.

Scottish Qualifications Authority (SQA) (1997-2006) *Annual Reports and Statistics*. From http://www.sqa.org. Earlier reports available as Scottish Examination Reports, Dalkeith, Edingburgh (1962-1996).

Scottish Science Advisory Committee (SSAC) (2003) *Why Science Education Matters: Supporting and Improving Science Education in Scottish Schools*, Scotland: Scottish Science Advisory Committee.

Searleman, A and Hermann, D. (1994) Effect of arousal, stress, and emotion. In Searleman, A. and Hermann, D. *Memory from a Broader Perspective*, MacGraw-Hill, 170-194.

Selepeng, D. B. (1995) *Teaching and Learning Science in a Second Language*, M.Sc. Thesis, University of Glasgow.

Selepeng, D. B. (2000) *An Investigation of Intellectual Growth in Undergraduate Biology Students Using the Perry Scheme*, Ph.D. Thesis, University of Glasgow.

Sequeira, M. and Leite, L. (1990) On relating macroscopic phenomena to microscopic particle at the junior high school level. In Lijnse, P. L., Licht, P., Vos, W. and Vaarlo, A. J. (Ed) *Relating Macroscopic Phenomena to Microscopic Particles*, Utrecht, Netherlands: CD-Press, 220-232.

Seymure, J. and Longden, B. (1991) Respiration - That's breathing isn't it? *Journal of Biological Education*, 23, 77-184.

Shamos, M. H. (1995) *The Myth of Scientific Literacy*, New Brunswick, NJ: Rutgers University Press.

Shavelson, R. (1972) Some aspects of the correspondence between content structure and cognitive structure in physics instruction. *Journal of Educational Psychology*, 63(3), 225-234.

Shavelson, R. (1974) Methods for examining representations of a subject matter structure in a student's memory. *Journal of Research in Science Teaching*, 11(3), 231-249.

Shayer, M. and Adey, P. P. (1981) *Toward a Science of Science Teaching: Cognitive Development and Curriculum Demand*, London: Heinemann Educational Books.

Shen, B. S. P. (1975) Science literacy. *American Scientist*, 63, 265-268.

Shortland, M. (1988) Advocating science: Literacy and public understanding. *Impact of Science on Society*, 38, 305-316.

Silverman, A. J., Adevai, G. and McGough, W. E. (1966) Some relationships between handedness and perception. *Journal of Psychosomatic Research*, 10, 151-158.

Simpson, M. and Arnold, B. (1982) The inappropriate use of subsumers in biology learning. *European Journal of Science Education*, 4(2), 173-182.

Sirhan, G. and Reid, N. (2001) Preparing the mind of the learner - Part 2. *University Chemistry Education*, 5, 52-58.

Slack, S. J. and Stewart, J. H. (1990) High school students' problem-solving performance on realistic genetics problems. *Journal of Research in Science Teaching*, 27, 55-67.

Slavin, R. E. (2000) *Educational Psychology* (6th Ed), Boston, USA: Allyn and Bacon.

Smith, M. U. (1991) *Toward and Unified Theory of Problem Solving: Views from the Content Domains*, Hillsdale, NJ: Erlbaum.

Solomon, J. (1987) Social influences on the construction of pupil's understanding of science. *Studies in Science Education*, 14, 63-82.

Solomon, J. (1989) The social construction of school science. In Millar, R. (Ed) *Doing Science: Images of Science in Science Education*, New York: Flamer Press.

Solomon, J. (1993) *Teaching Science, Technology and Society*, Buckingham, UK: Open University Press.

Solomon, J. and Aikenhead, G. (1994) *STS Education: International Perspectives on Reform*, New York: Teachers College Press.

Solso, R. L. (1998) *Cognitive Psychology* (5th Ed), Boston, USA: Allyn and Bacon.

Steward, J. H. (1979) Content and cognitive structure: Critique of assessment and representation techniques used by science education researchers. *Science Education*, 63, 395-406.

Steward, J. H. (1982a) Difficulties experienced by high school students when learning basic Mendelian genetics. *The American Biology Teacher*, 44(2), 80-84.

Steward, J. H. (1982b) Two aspects of meaningful problem solving in science. *Science Education*, 66, 731-749.

Steward, J. H. (1983) Student problem solving in high school genetics. *Science Education*, 67, 532-540.

Steward, J. H., Hafner, D. and Dale, M. (1990) Students' alternative views of meiosis. *The American Biology Teacher*, 52, 228-232.

Su, W.Y. (1991) *A Study of Student Learning Through Lectures Based on Information Processing Theory*, Ph.D. Thesis, University of Glasgow.

Sutherland, P. (1992) *Cognitive Development Today: Piaget And His Critics*, London, U.K: Paul Chapman Publishing Ltd.

Sutman, F. X. (1996) Scientific literacy: A functional definition. *Journal of Research in Science Teaching*, 33, 459-460.

Sutton, C. (1980) The learner's prior knowledge: A critical review of techniques for probing its organization. *European Journal of Science Education*, 2, 107-120.

Sutton, C. (1996) Beliefs about science and beliefs about language. *International Journal of Science Education*, 18(1), 1-18.

Tamir, P. P., Gal-Choppin, R. and Nussinovitz, R. (1980) How do intermediate and junior high school students conceptualise living and non-living? *Journal of Research in Science Teaching*, 18(3), 242-248.

Tennant, M. (1988) *Psychology and Adult Learning*, London: Routledge.

Terrell, S. T. (2002) *The Use of Cognitive Style as a Predictor of Membership in Middle and High School Programs for the Academically Gifted.* Paper presented at the Annual meeting of the American Educational. Research Association, New Orleans, Louisiana.

Thompson, B. and Melancon, J. G. (1987) Measurement characteristics of the GEFT. *Educational and Psychological Measurement*, 47, 765-772.

Tinajero, C. and Paramo, M. (1997) Field-dependence and independence and academic achievement: A re-examination of their relationship. *British Journal of Educational Psychology*, 67(2), 199-212.

Tinajero, C. and Paramo, M. (1998) Field dependence-independence, cognitive style and academic achievement: A review of research and theory. *European Journal of Psychology of Education*, 13(2), 227-251.

Tittle, C and Hill, R (1967) Attitude measurement and prediction of behaviour: An evaluation of conditions and measurement techniques. *Sociometry*, 30, 6-12.

Thomas, W. I. and Znaniecki, F. (1918) Context and diffusion of knowledge: A critique of eurocentrism. *The Polish Peasant in Europe and America*, New York: Dover.

Thomson, N. and Stewart, J. (1985) Secondary school genetics instruction: Making problem solving explicit and meaningful. *Journal of Biological Education*, 19(1), 53-62.

Tolman, R. R. (1982) Difficulties in genetics problem solving. *The American Biology Teacher*, 44, 525-527.

Vygotsky, L. S. (1962) *Thought and Language*, New York: Wiley.

Vygotsky, L. (1986) *Thought and Language* (A. Kozulin, Trans.), Cambridge: MA, The MIT Press.

White, R. T. (1988) *Learning science*, New York: Basil Blackwell Inc.

White, R. and Gunstone, R. (1992) *Probing Understanding*, London, The Flamer Press.

Willington, J. (1983) A taxonomy of scientific words. *School Science Review*, 64(229), 767-773.

Willington, J. (1988) Balanced science: Where do you stand? *School Science Review*, 70(251), 145-147.

Witkin, H. A. (1964) Origins of cognitive style. In Sheerer, C. (Ed) *Cognition: Theory, Research, Promise*, New York: Harper and Row.

Witkin, H. A. (1974) *Psychological Differentiation: Studies of Development*, New York, USA: Wiley.

Witkin, H. A. (1978) *Cognitive Style in Personal and Cultural Adaptation*, Worcester, Mass: Clark University Press.

Witkin, H. A., Dyk, R. B., Faterson, H. F., Goodenough, D. R. and Karp, S. A. (1962) *Psychological differentiation*, New York: Wiley.

Witkin, H. A., Dyk, R. B., Faterson, H. F., Goodenough, D. R. and Karp, S. A. (1974) *Psychological differentiation. Studies of development*, New York: Lawrence Erlbaum Associates Inc.

Witkin, H. A. and Goodenough, D. R. (1981) *Cognitive Styles: Essence and Origins Psychological Issues Monograph 51*. New York: International Universities Press.

Witkin, H. A., Goodenough, D. R. and Cox, P. (1977) Field dependence and field independence cognitive styles and their educational implications. *Review of Educational Research*, 47, 1-64.

Witkin, H. A., Oltman, P., Raskin, E. and Karp, S. (1971) *Group Embedded Figures Test Manual*, Palo Alto, USA: CP Press.

Wood-Robinson, C. (1994) Young peoples' ideas about inheritance and evolution. *Study in Science Education*, 24, 29-47.

Wood-Robinson, C. (2000) Young people's understanding of the nature of genetic information in the cells of an organism. *Journal of Biology Education*, 35(1), 29-36.

Wood-Robinson, C., Lewis, J., Driver, R. and Leach, J. (1997) Young people's understanding of the nature of genetic information in the cells of an organism. *European Science Education Research Association*, Rome, 2-6 Sept.

Yager, R. E. (1992a) Science-technology-society as reform. In Yager, R. E. (Ed) *The Status of STS: Reform Efforts Around the World*, ICASE 1992 Yearbook, Knapp Hill, South Harting, Petersfield, UK: International Council of Associations for Science Education.

Yager, R. E. (1992b) *The Science, Technology, Society Movement*, Washington, DC: National Science Teachers Association.

Yang, M. (2000) *Problem Solving in Chemistry at Secondary School*. Ph.D. Thesis, University of Glasgow.

Youniss, J. (1980) *Parents and Peers in Social Development*, Chicago: University of Chicago Press.

Zanna, M. P. and Rempel, J. K. (1988) Attitudes: A new look at an old concept. In Bar-Tal, D. and Kruglanski, A. W. (Ed) *The Social Psychology of Knowledge*, Cambridge, England: Cambridge University Press.

Zajonc, R. B. (1968) Attitudinal effects of mere repeated exposure. *Journal of Personality and Social Psychology Monograph Supplement*, 9(2), 1-27.

Zehavi, N. (1995) Integrating software development with research and teacher education. *Computer in the Schools*, 11(3), 11-24.

Zeidler, D. L. (2003) *The Role of Moral Reasoning and Discourse on Socioscientific Issues in Science Education*, Netherlands: Kluwer.

Ziane. M. (1990) *The Implication of Information Processing Theory to the Learning of Physics*, Ph.D. Thesis, University of Glasgow.

Zuckerman, D. M., Singer, D. G. and Singer, J. L. (1980) Children's television viewing, racial and sex-role attitudes. *Journal of Applied Social Psychology*, 10, 281-294.

List of Appendices

Appendix A

Figural intersection test with answers

Figural Intersection Test

Name: ___________ Sex: ☐ Boy ☐ Girl

This is a test of your ability to find the overlap of a number of simple shapes.

There are two sets of simple geometric shapes, one on the right and the other on the left. The set on the left contains the same shapes (as on the right) but overlapping, so that there exists a common area which is inside all of the shapes.

Look for and *shade* in the common *area of overlap*.

Note these points:

The shapes on the left may differ in size or position from those on the right, but they match in *shape* and *proportions*.

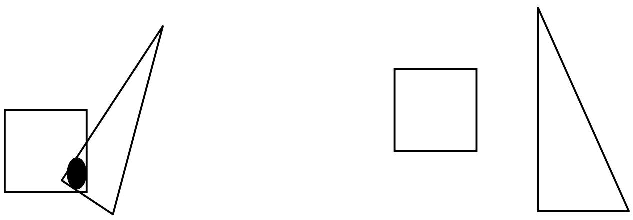
In some items on the left some extra shapes appear which are not present in the right hand set, and which do not form a common area of intersection with all of the other shapes. These are present to mislead you to ignore them.

The overlap should be shaded clearly by using a pen.

The results of this test will not affect your schoolwork in any way.

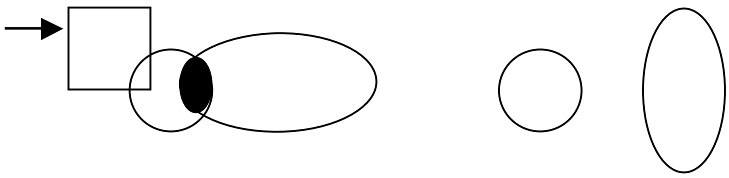
Here are some samples to get you started.

Example (1):

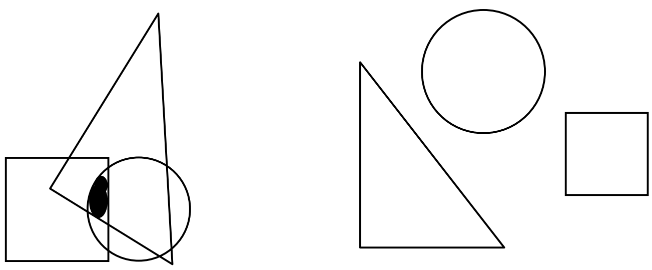


Example (2):

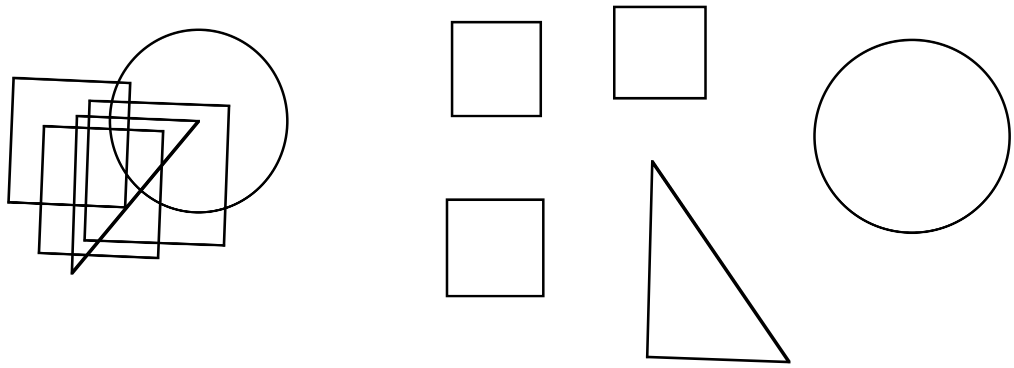
Irrelevant shape put in to confuse you!



Example (3):



Now attempt each of the items on the following sheets:

1	
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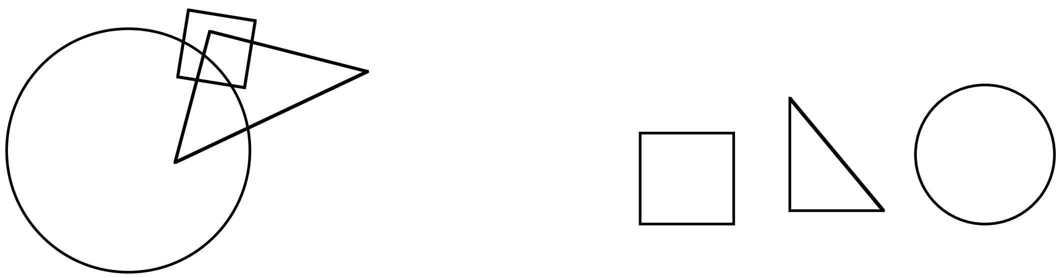
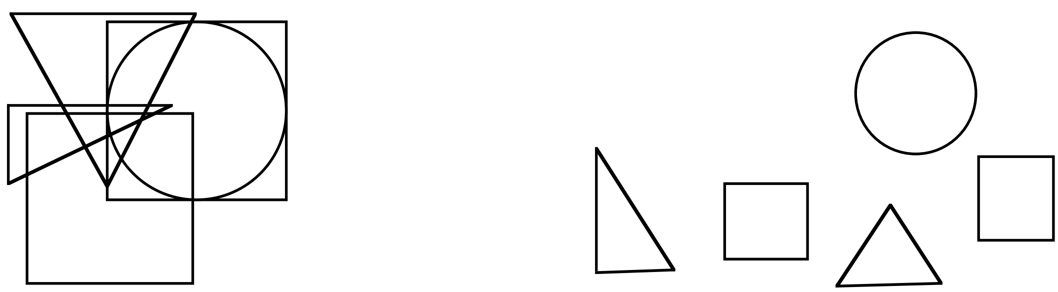
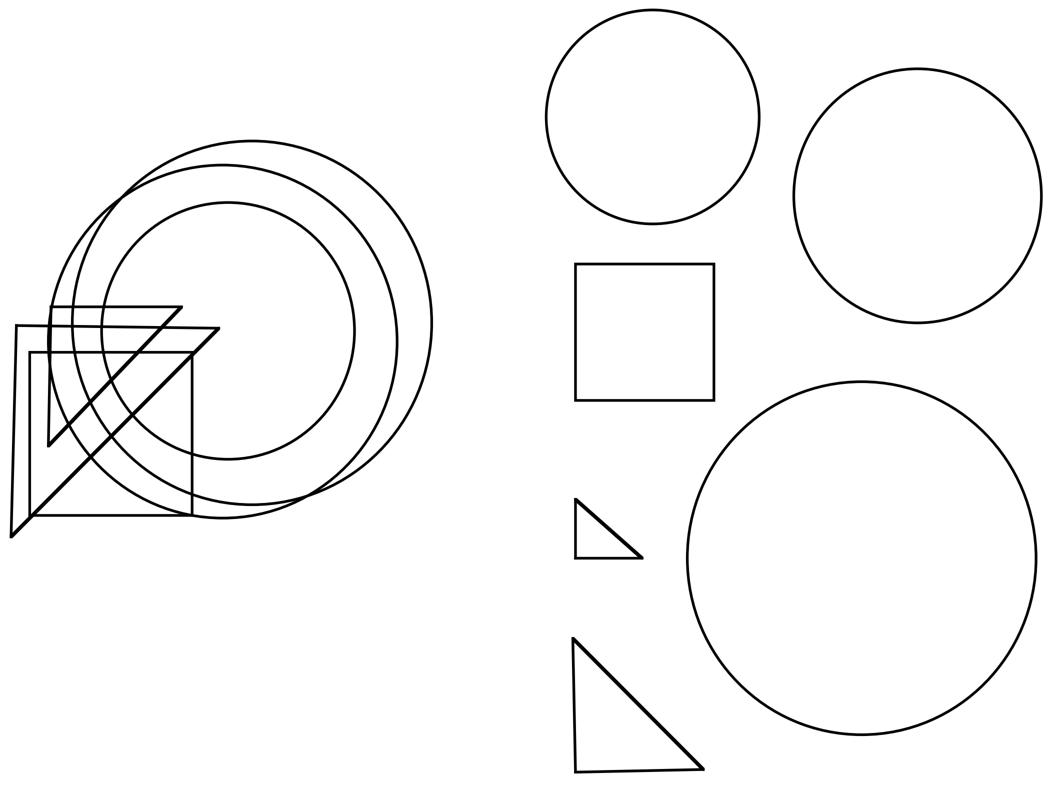
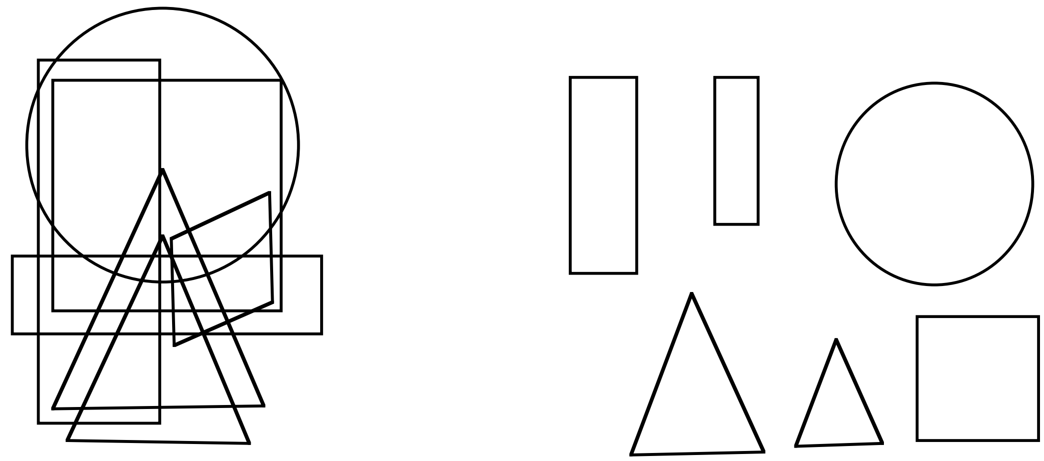
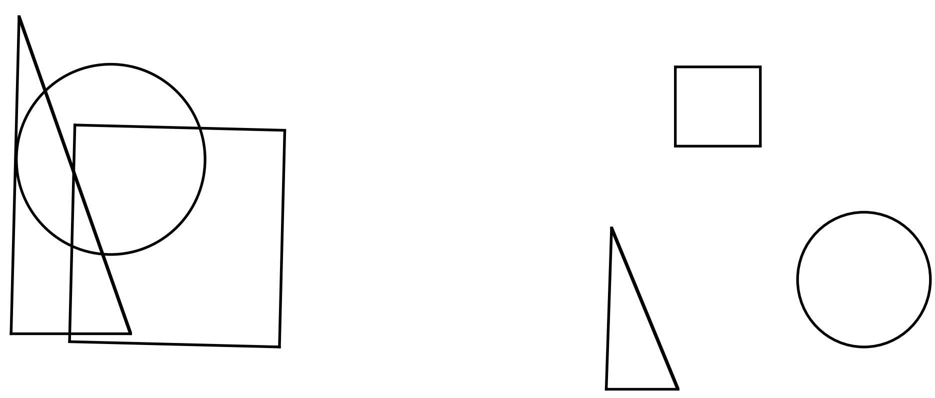
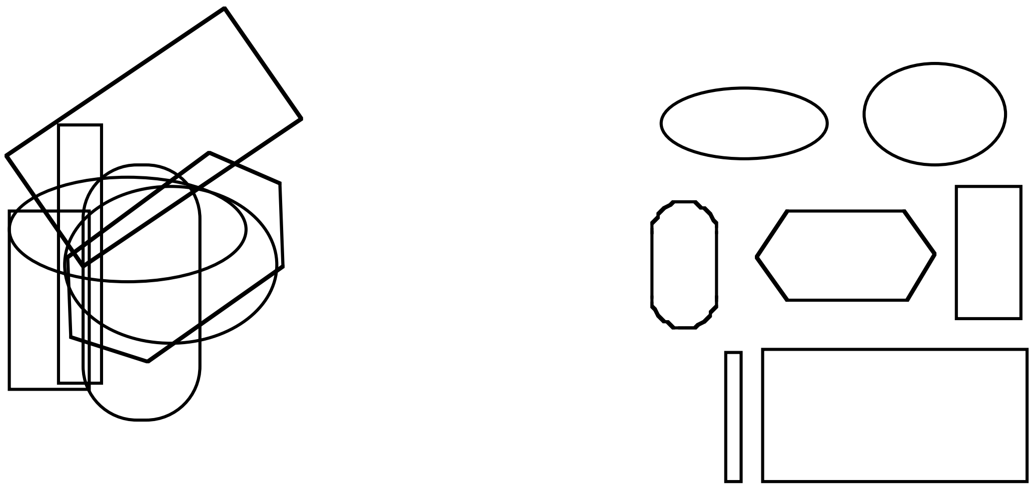
3	
4	

5	
6	
7	

8	
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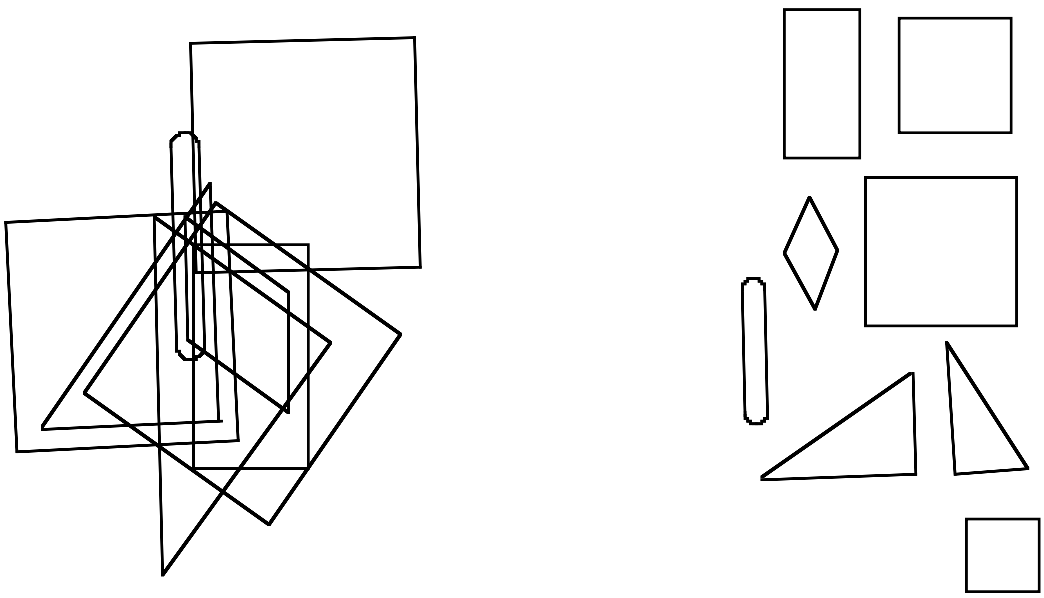
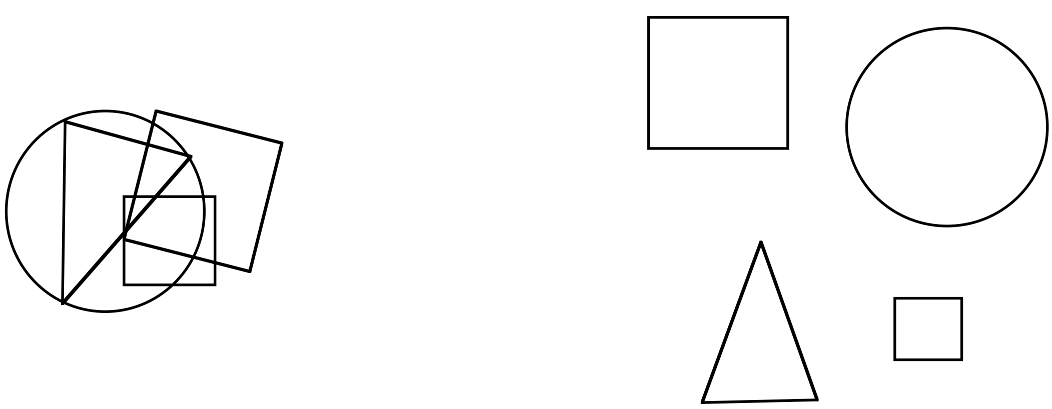
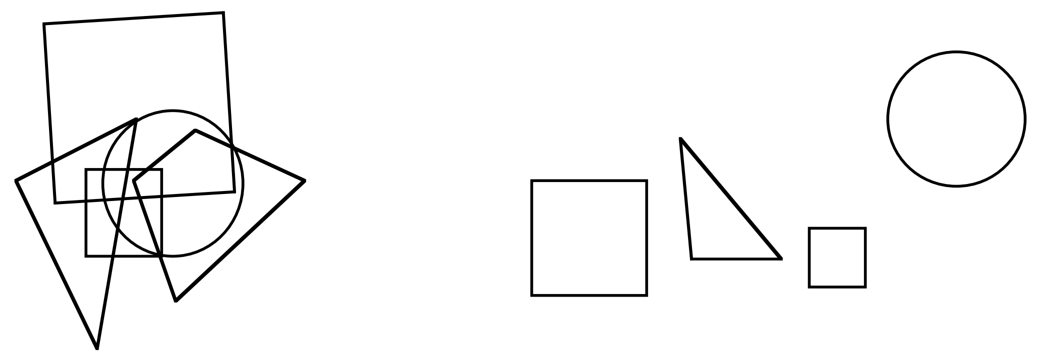
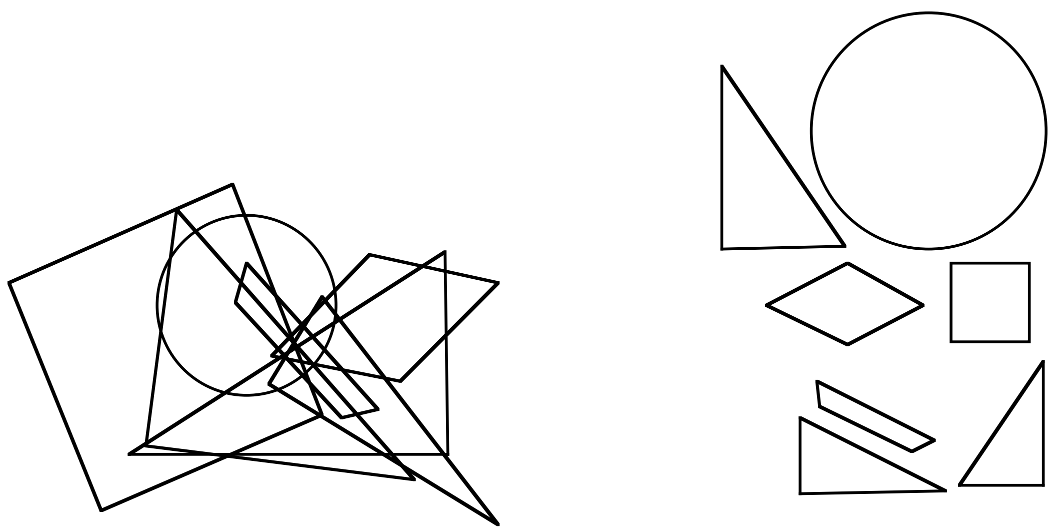
10	
11	

12	
13	
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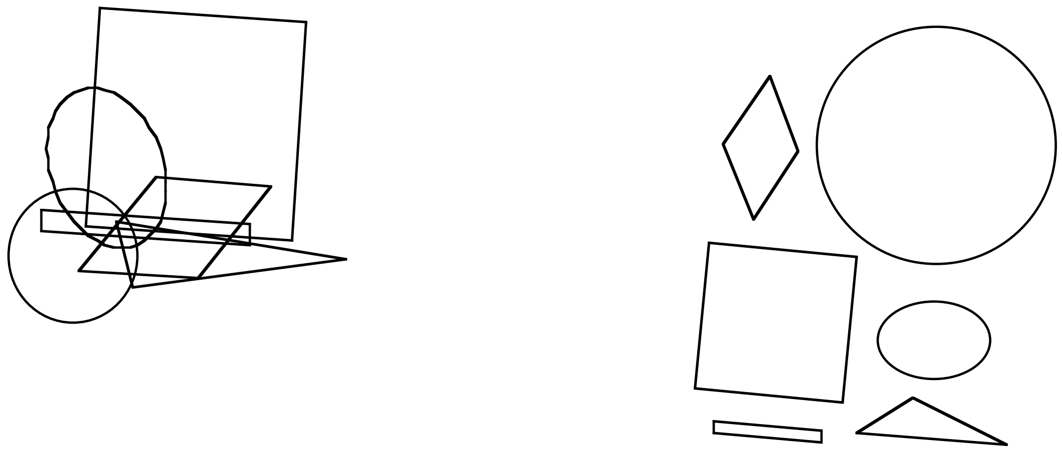
15	

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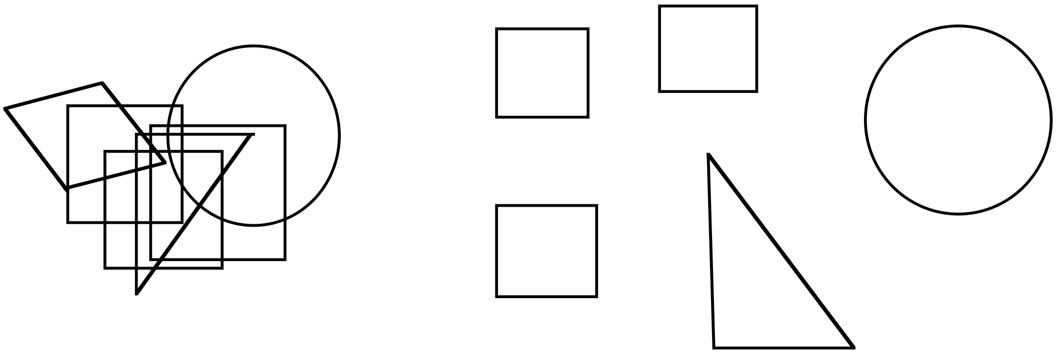
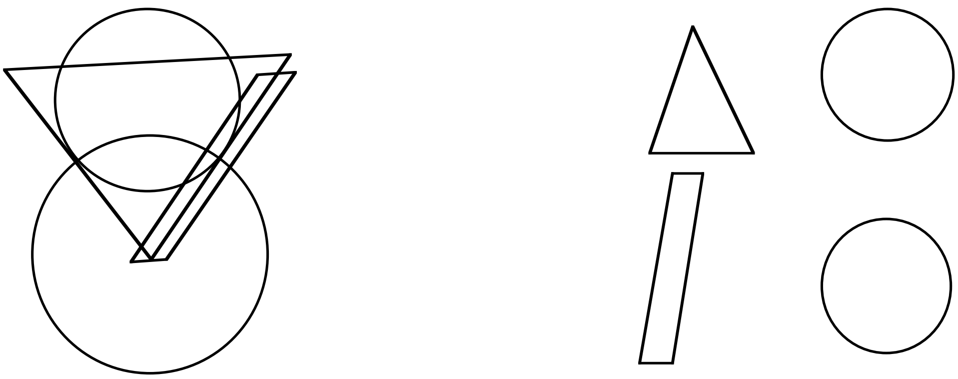
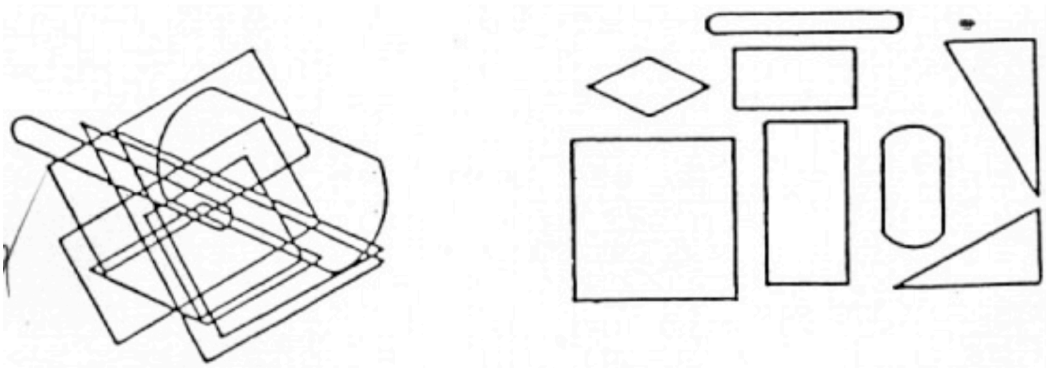
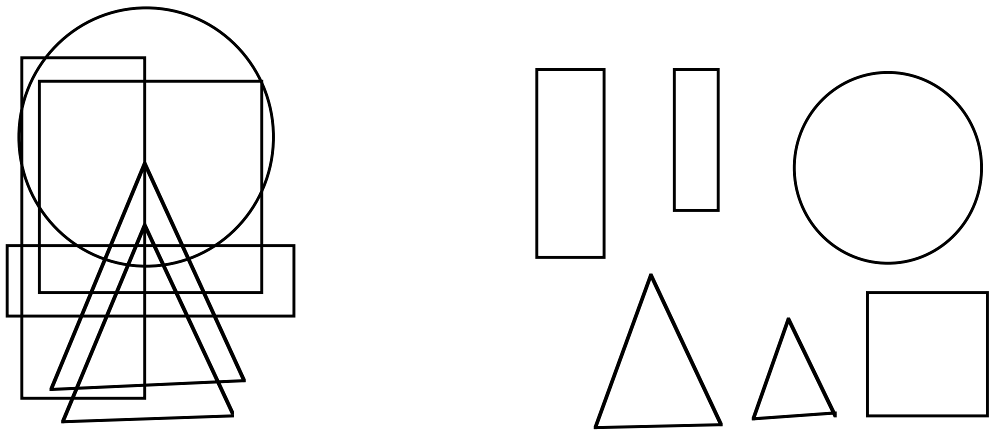
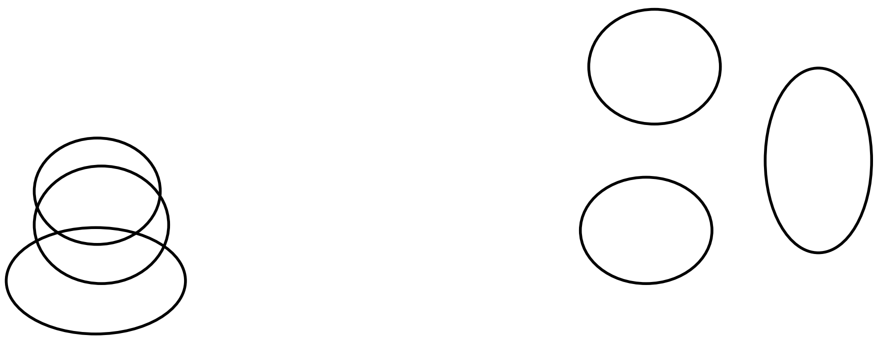
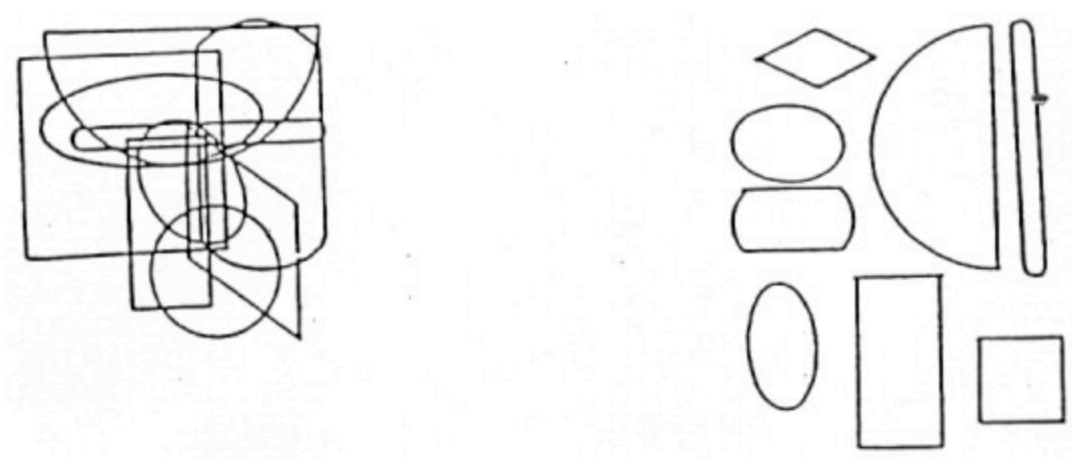
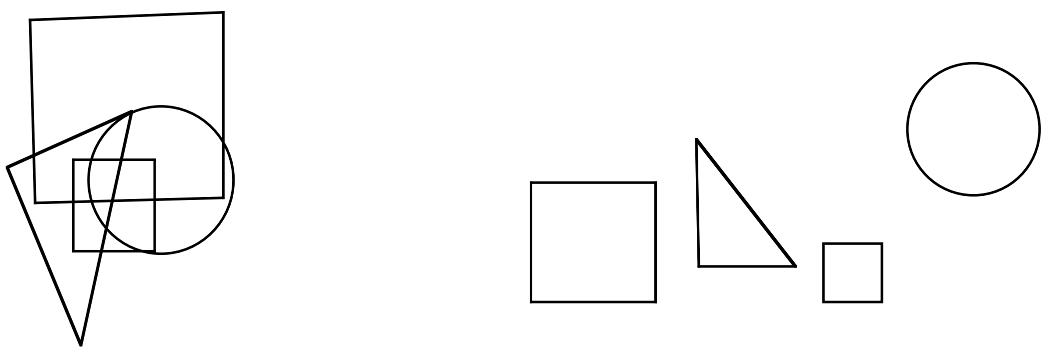
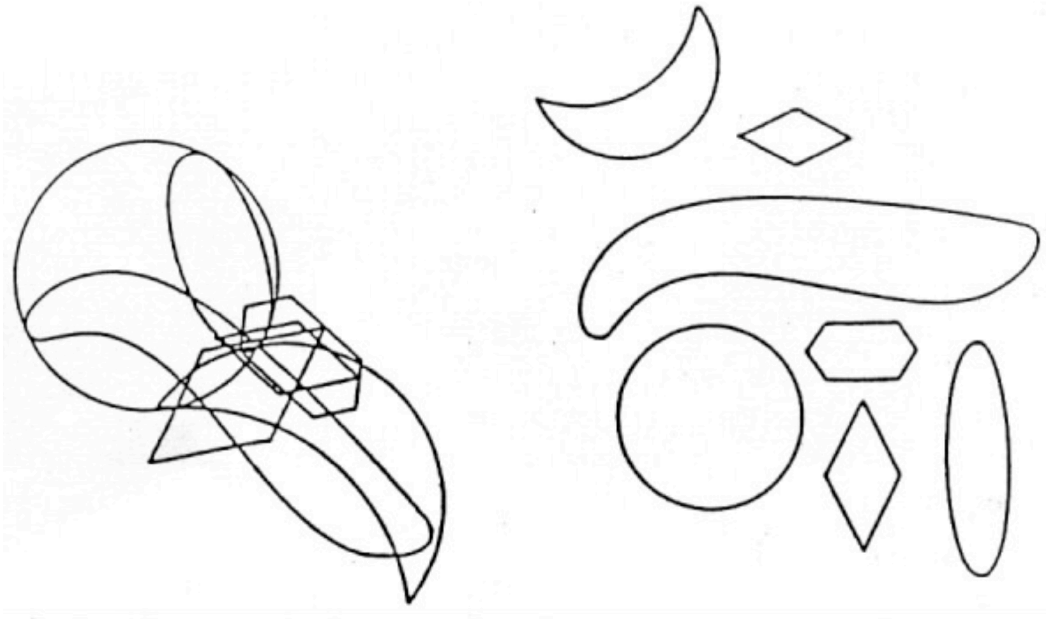
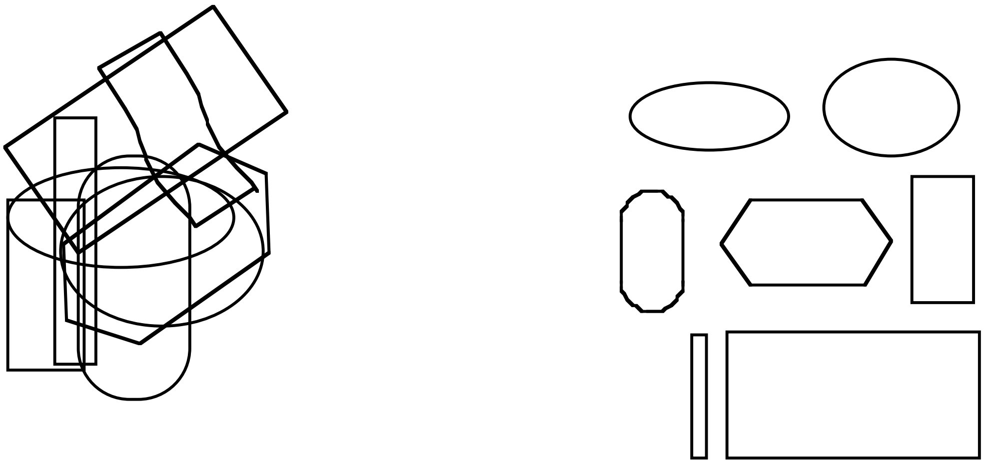
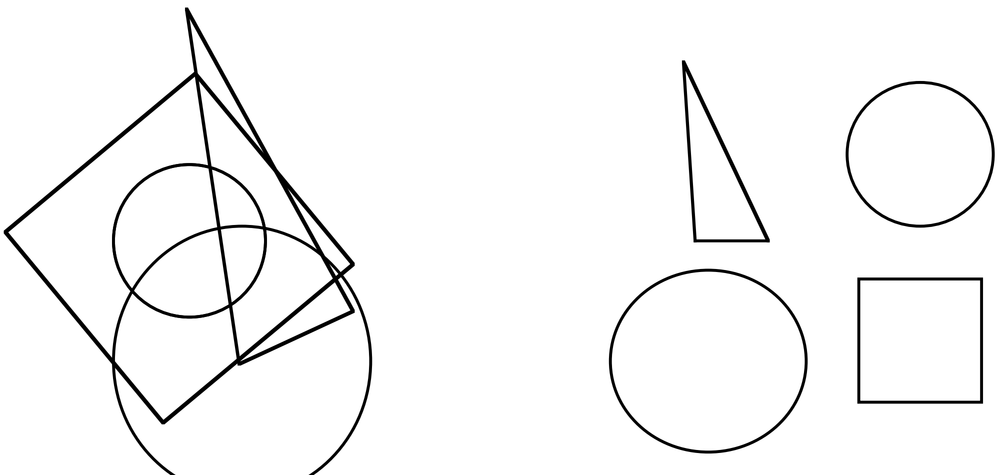
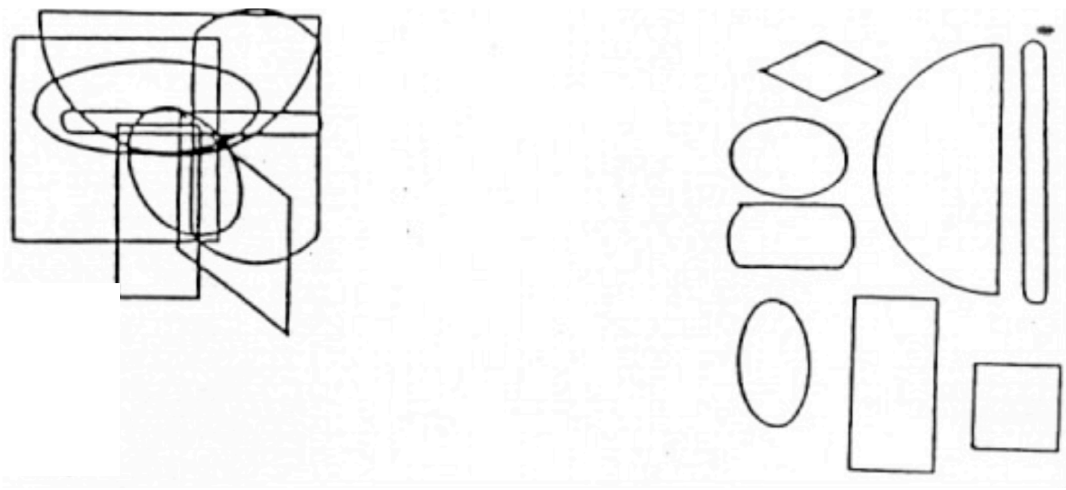
17	
18	
19	

20	
21	
22	
23	

24	
25	
26	

27	
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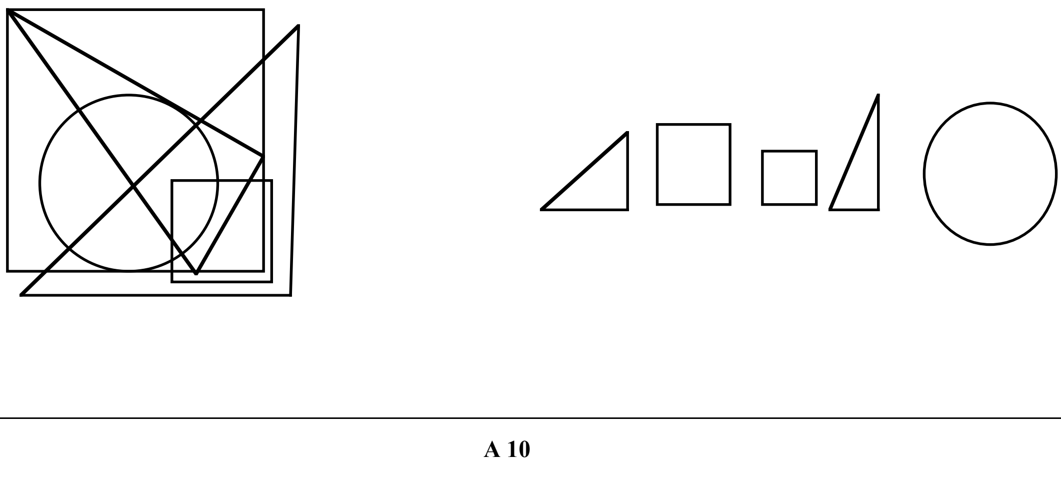
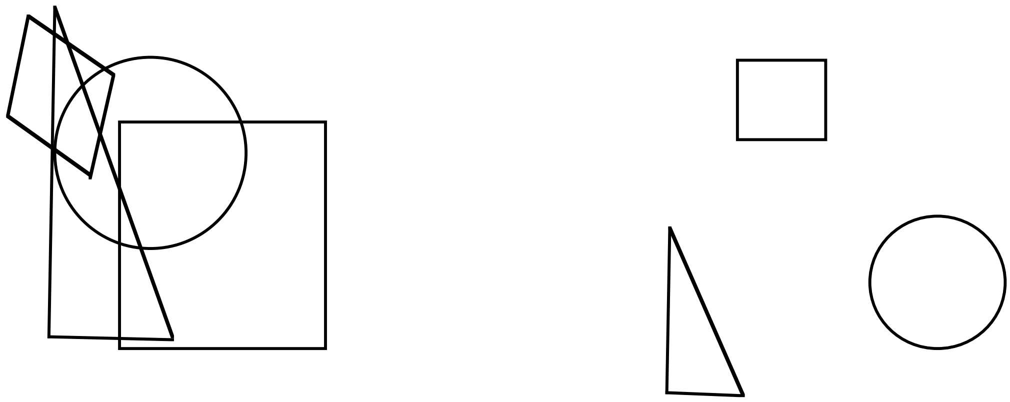
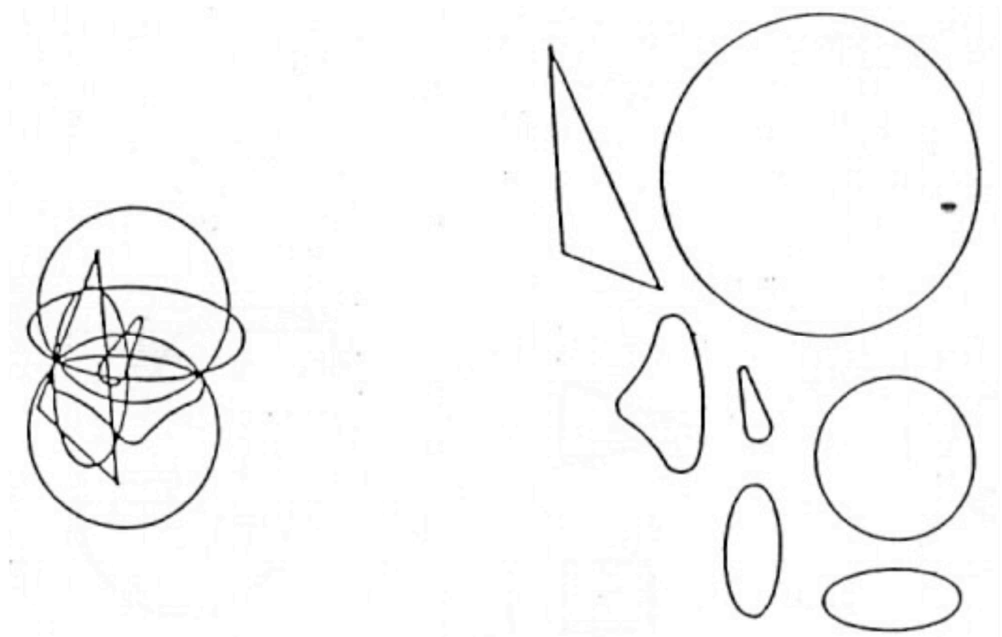
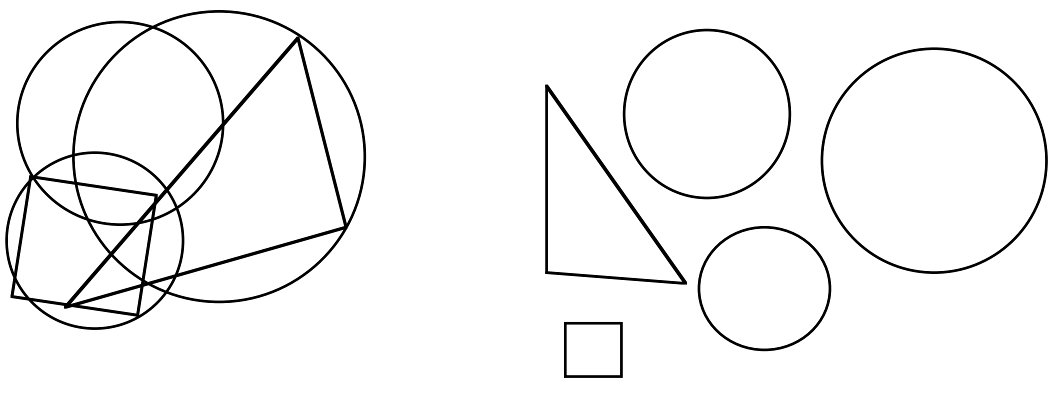
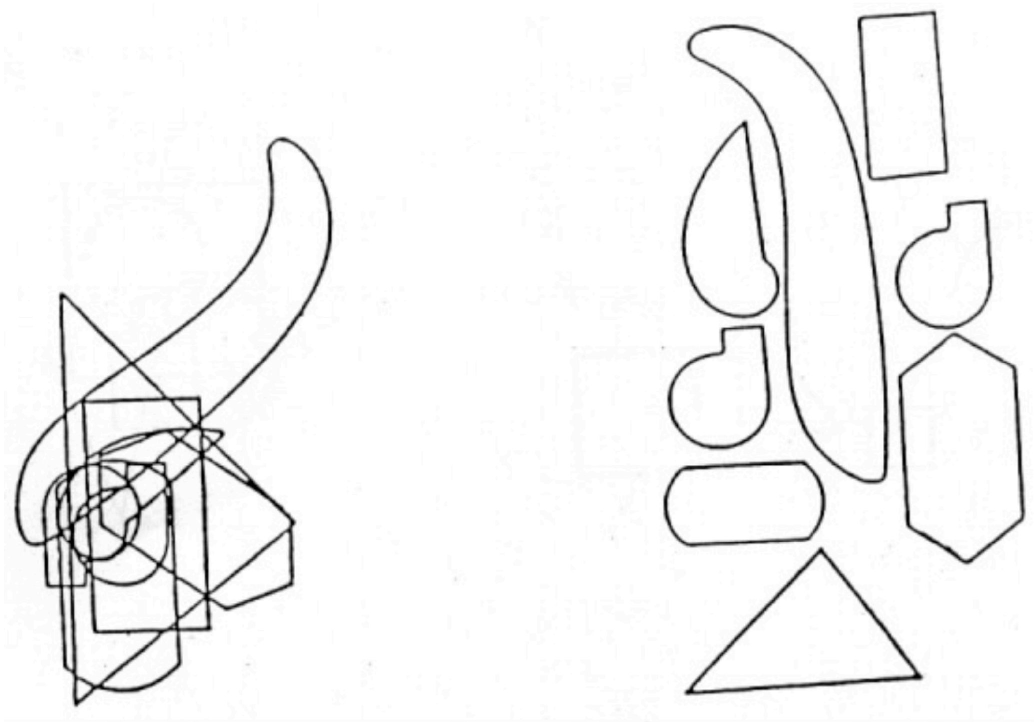
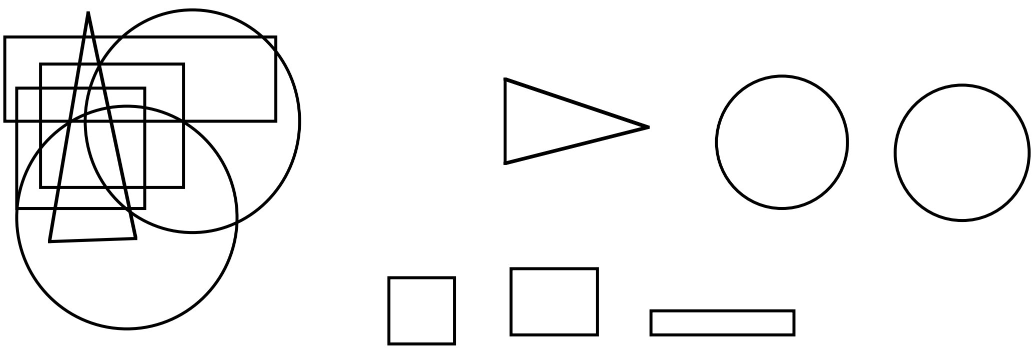
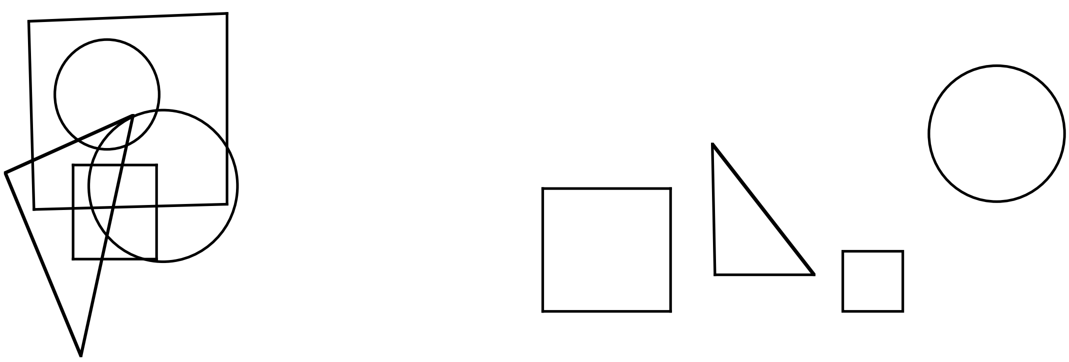
30	

31	
32	
33	

34	
35	
36	

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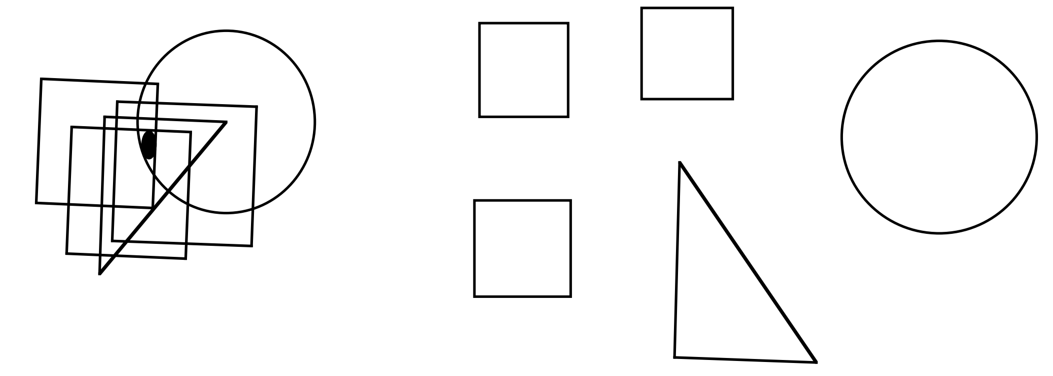
1	
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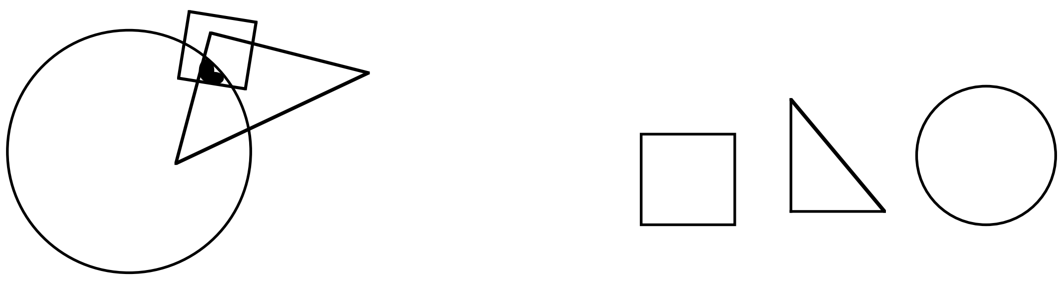
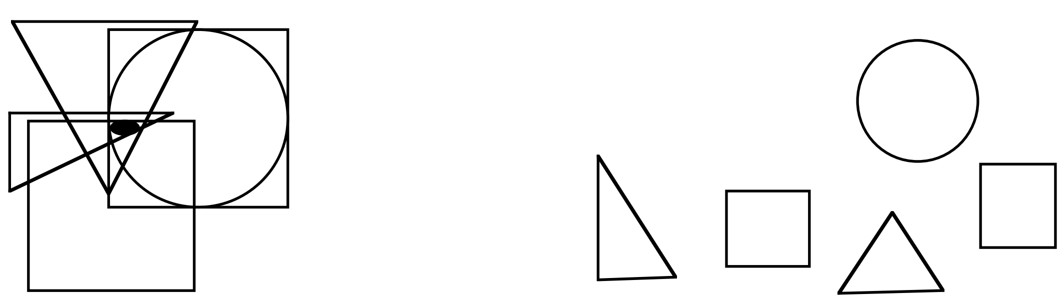
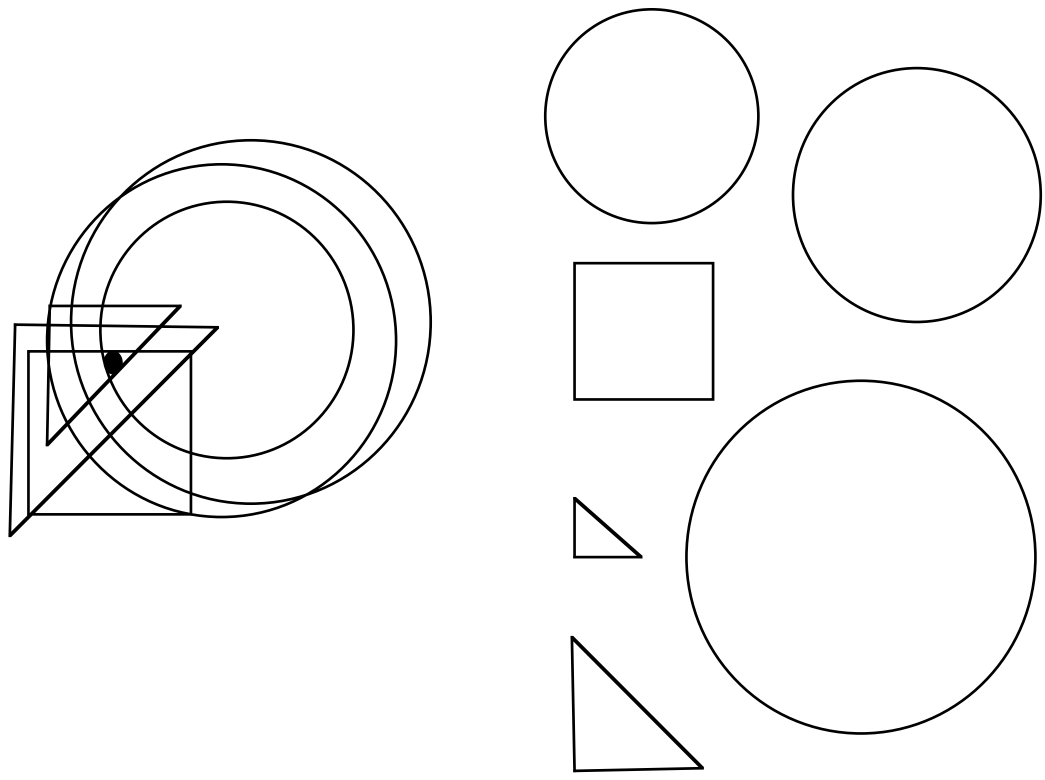
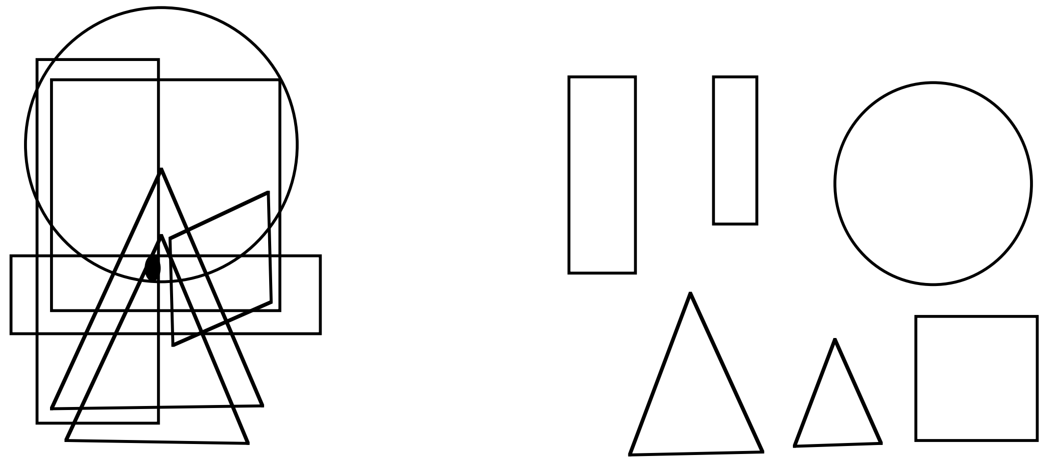
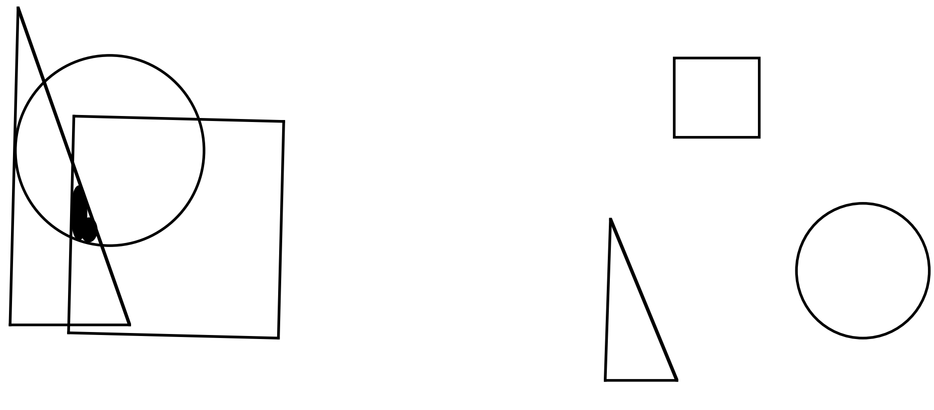
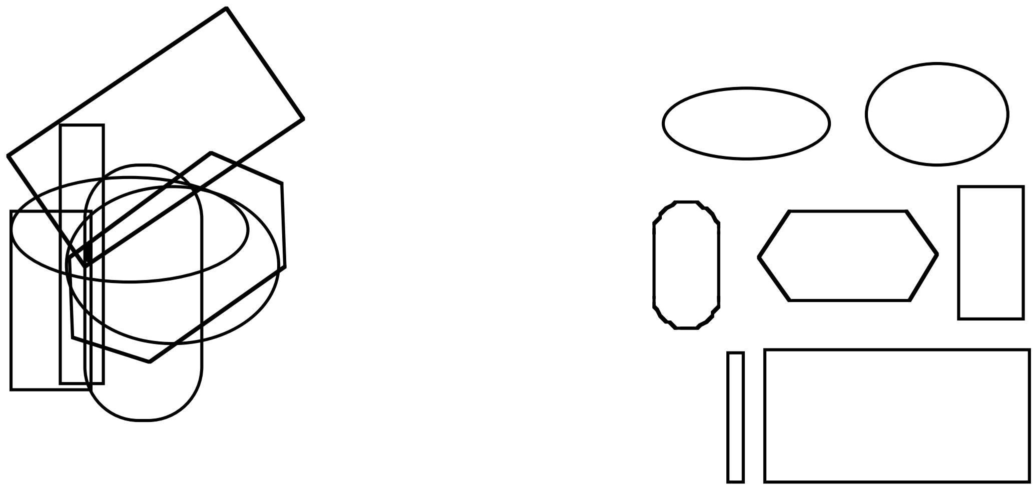
3	
4	

5	
6	
7	

8	
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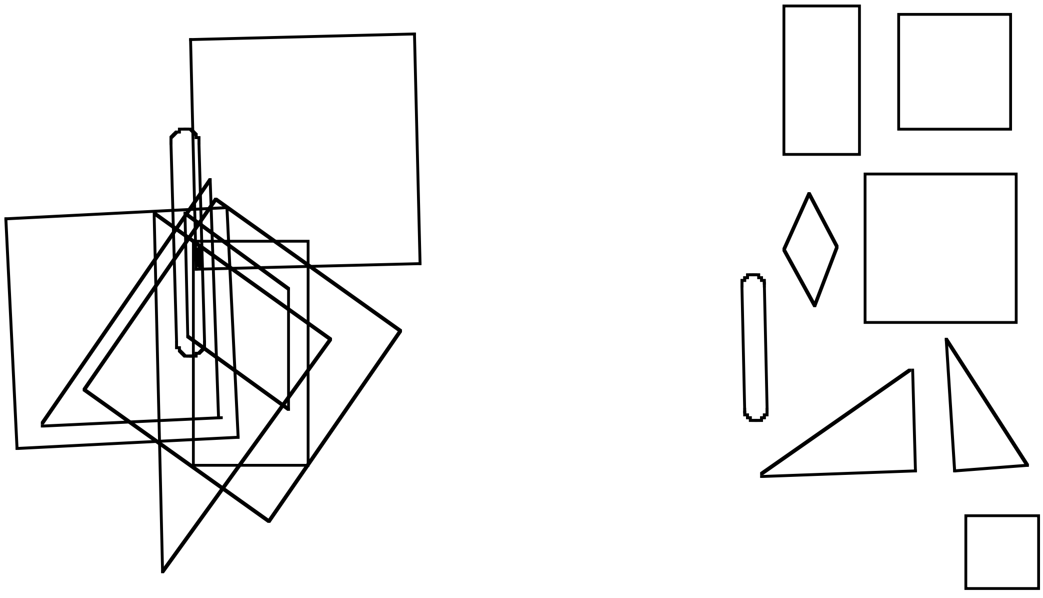
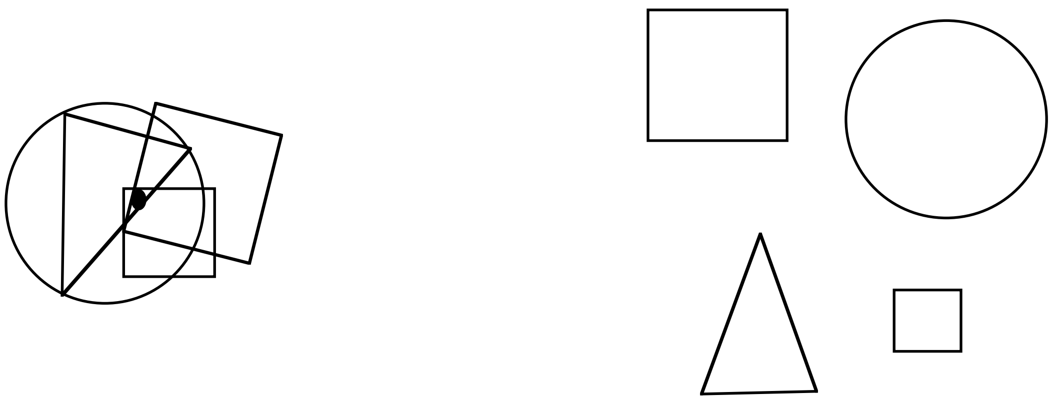
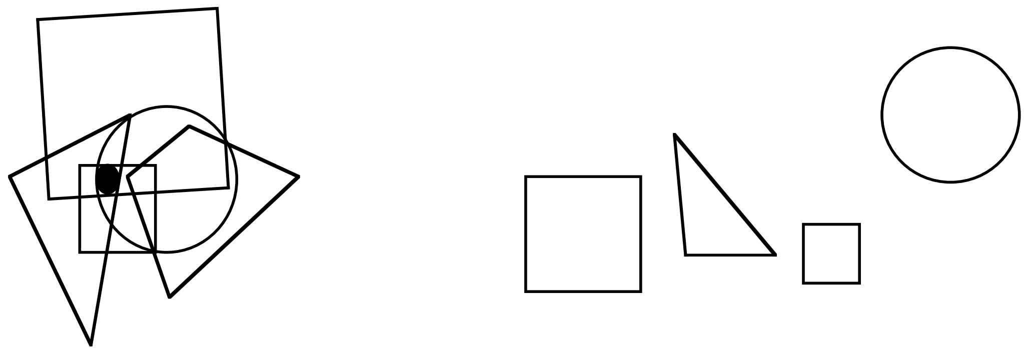
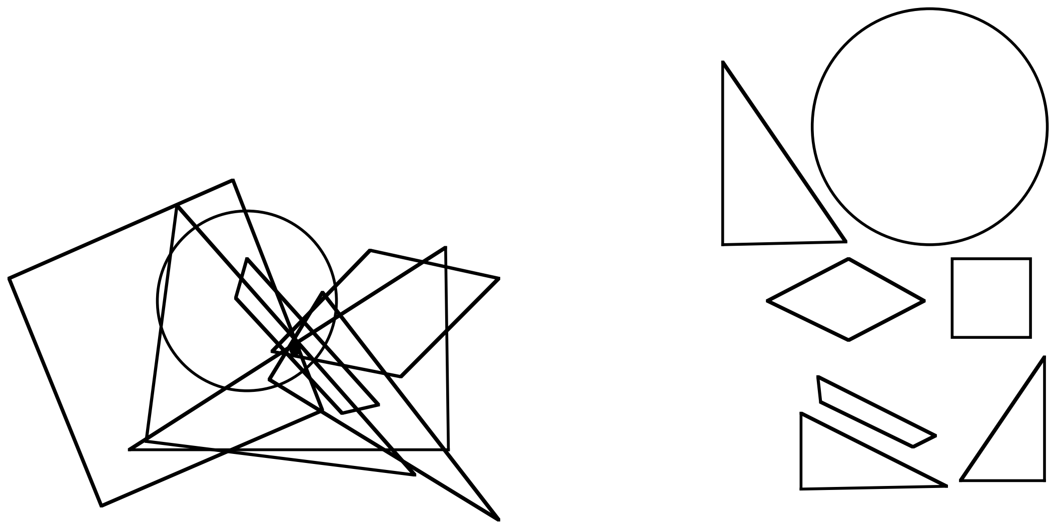
10	
11	

12	
13	
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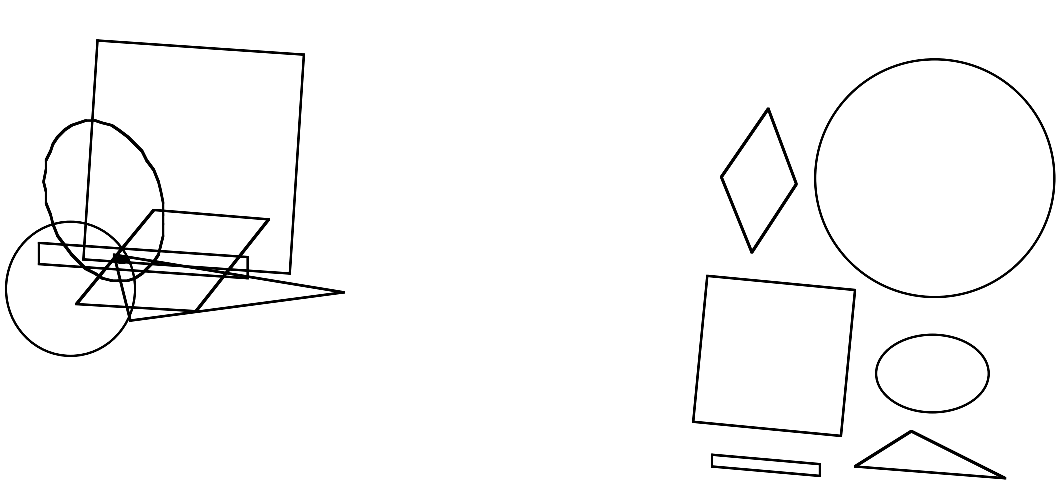
15	

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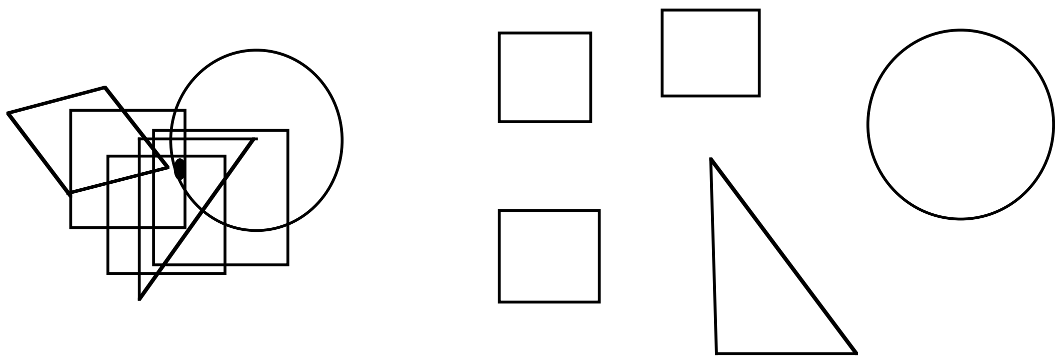
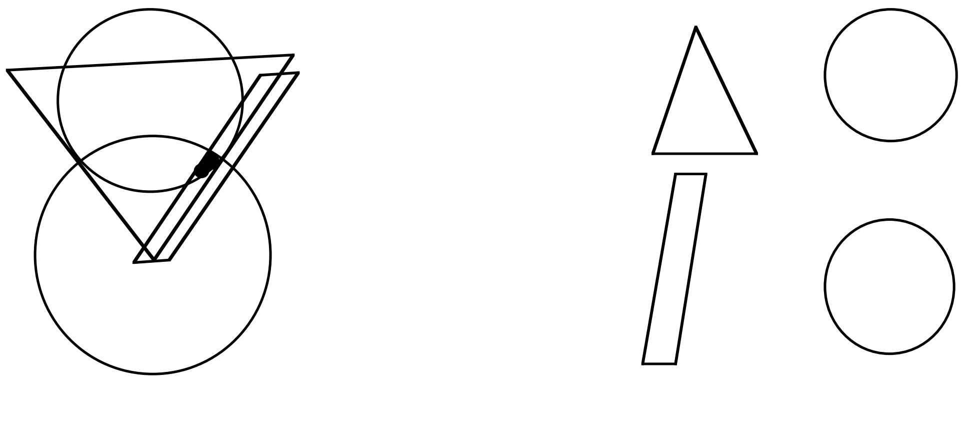
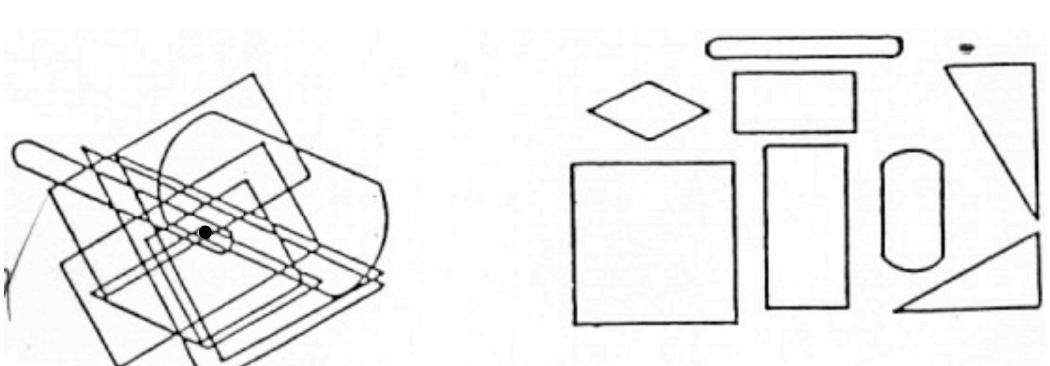
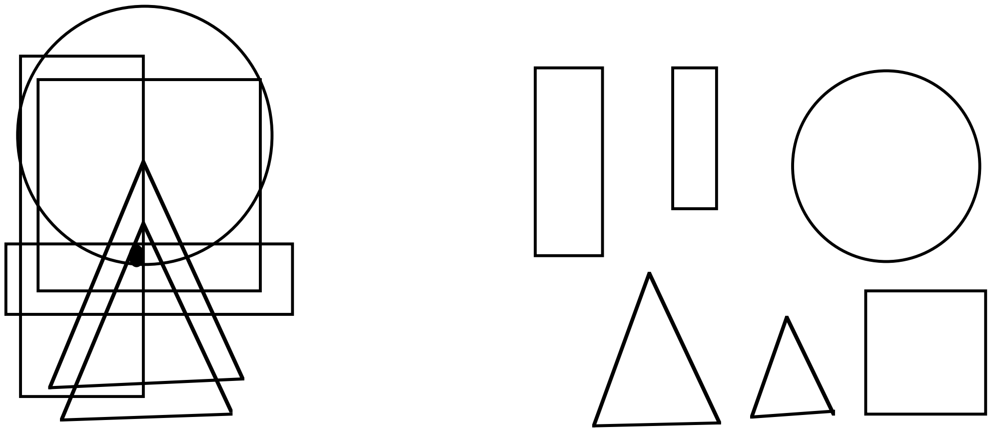
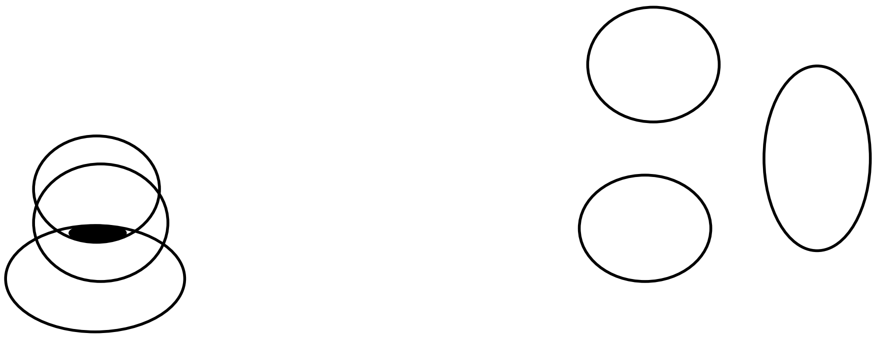
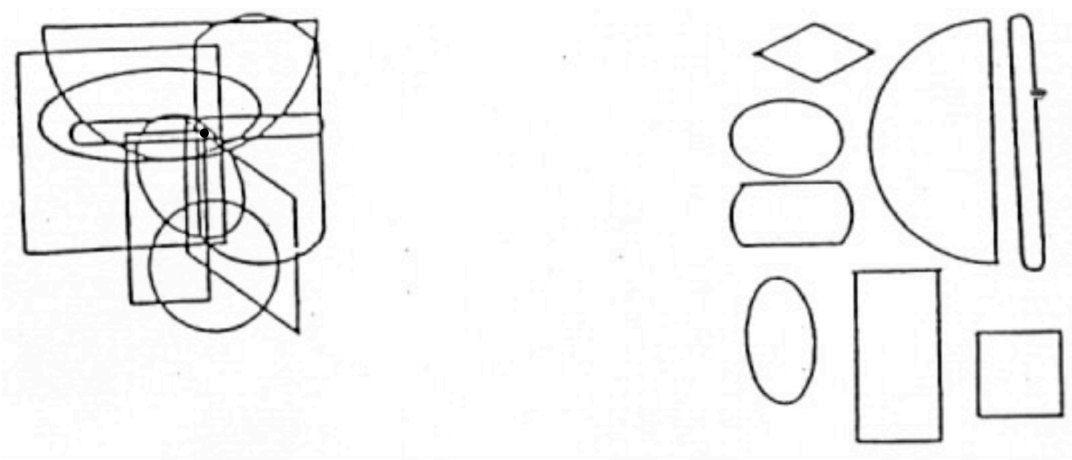
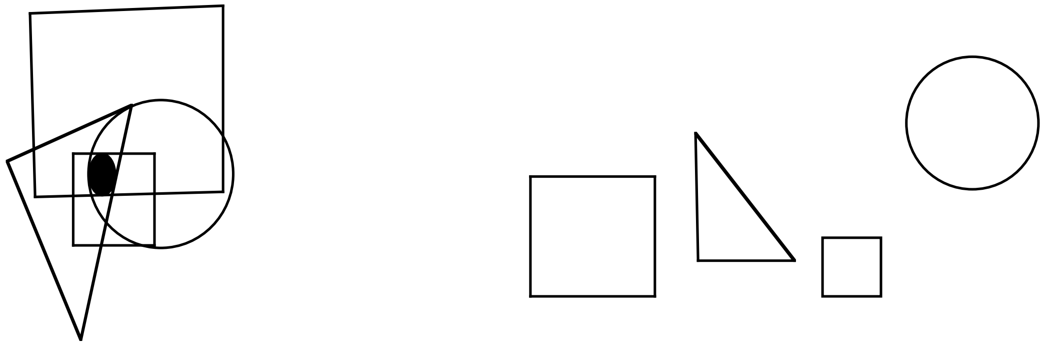
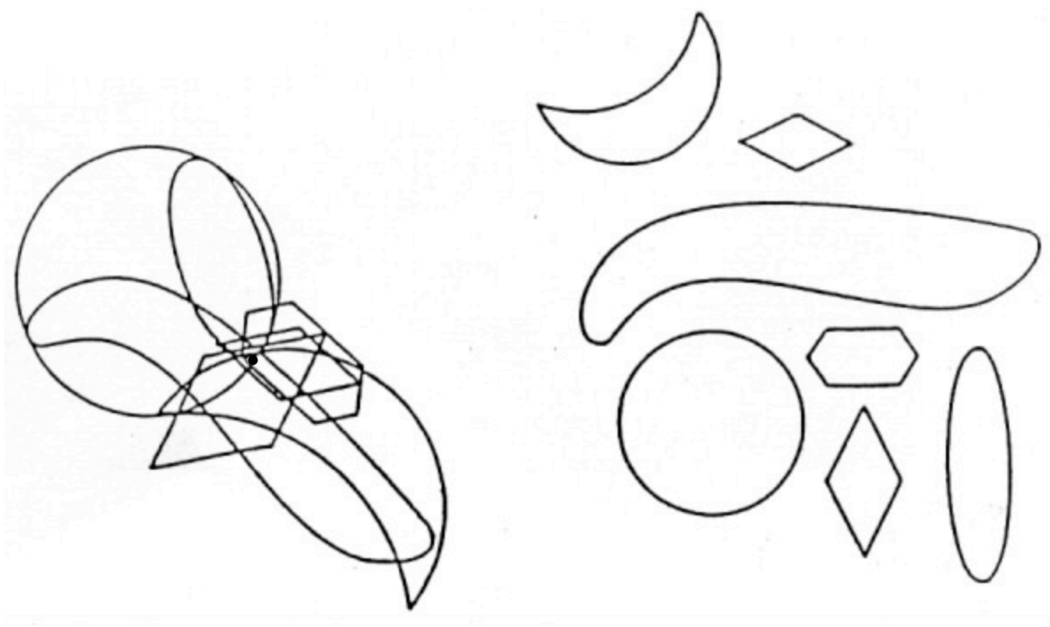
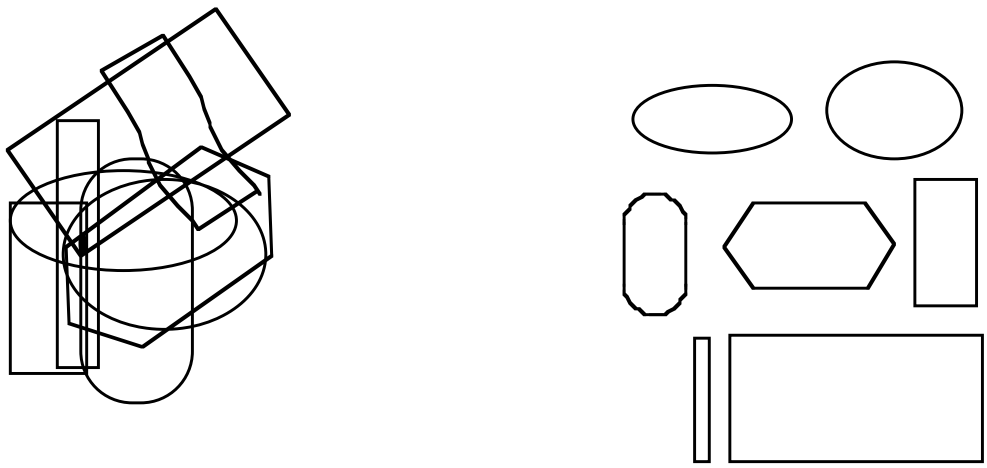
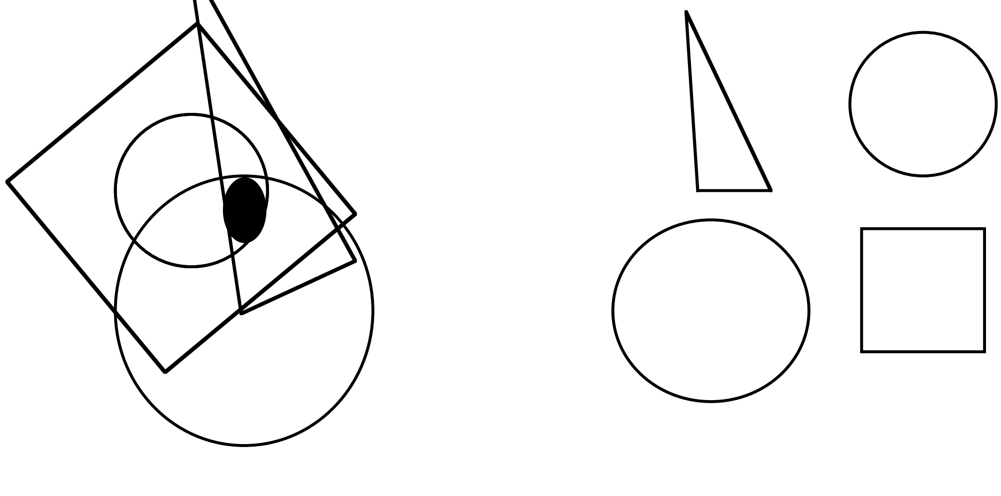
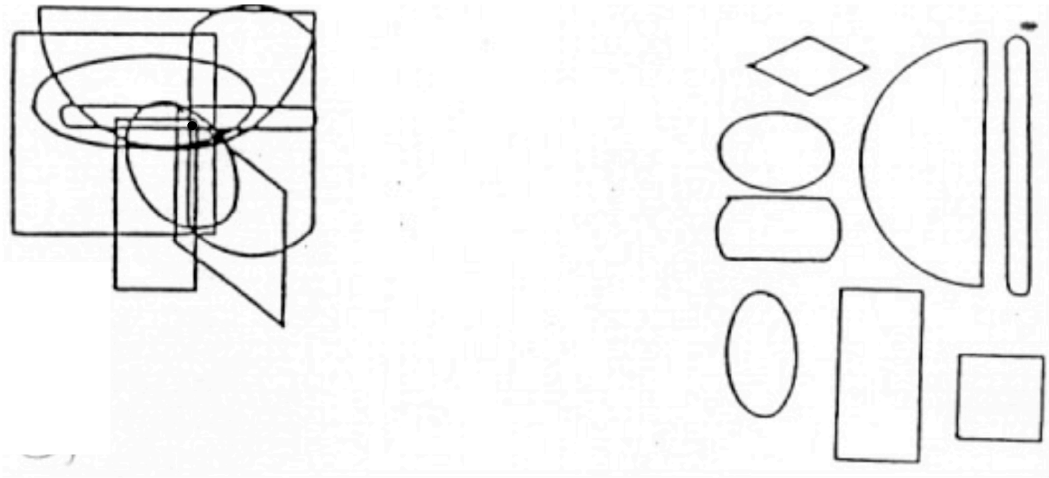
17	
18	
19	

20	
21	
22	
23	

24	
25	
26	

27	
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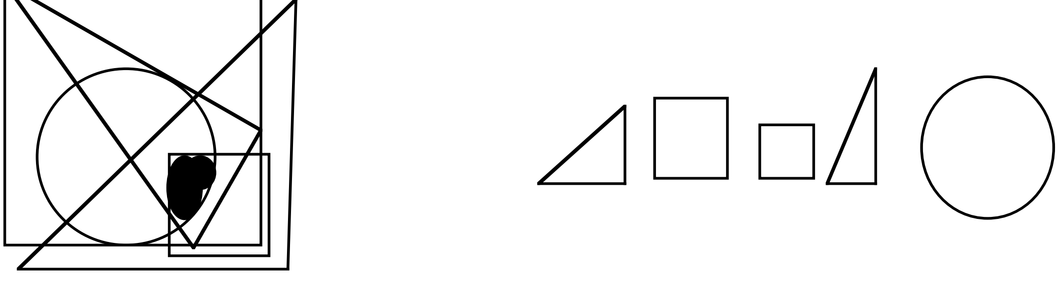
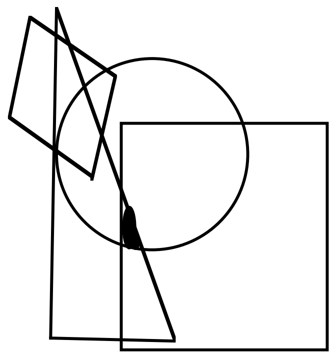
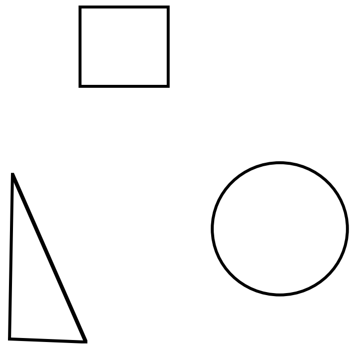
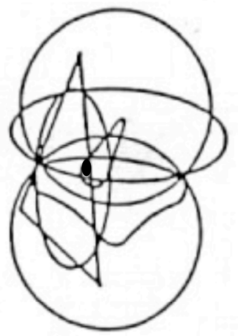
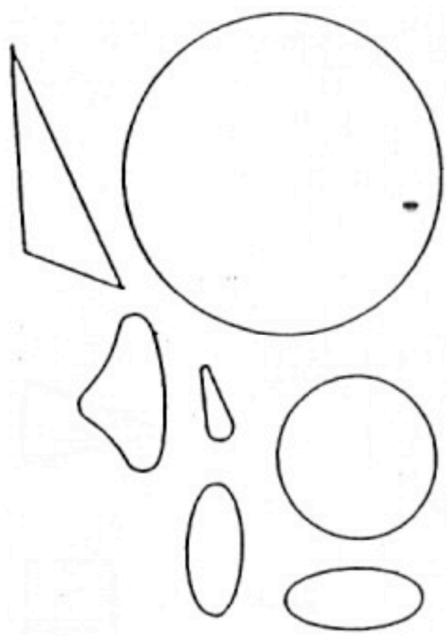
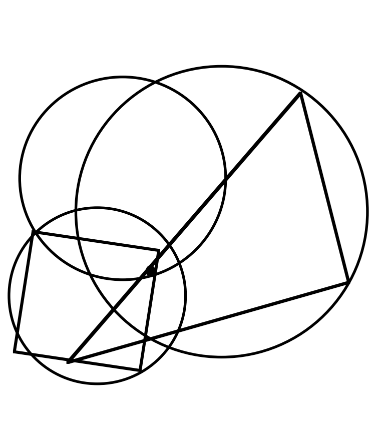
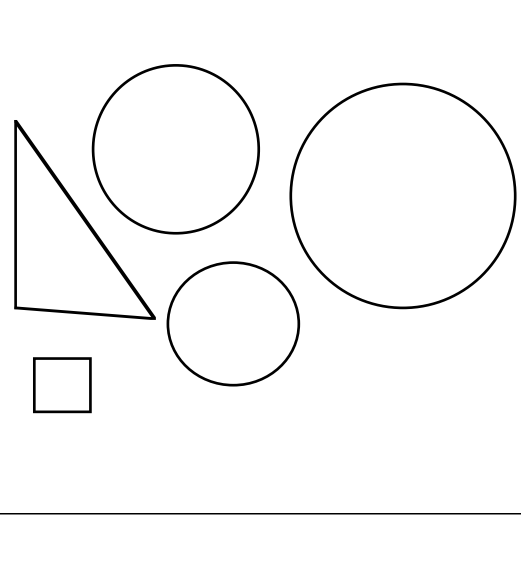
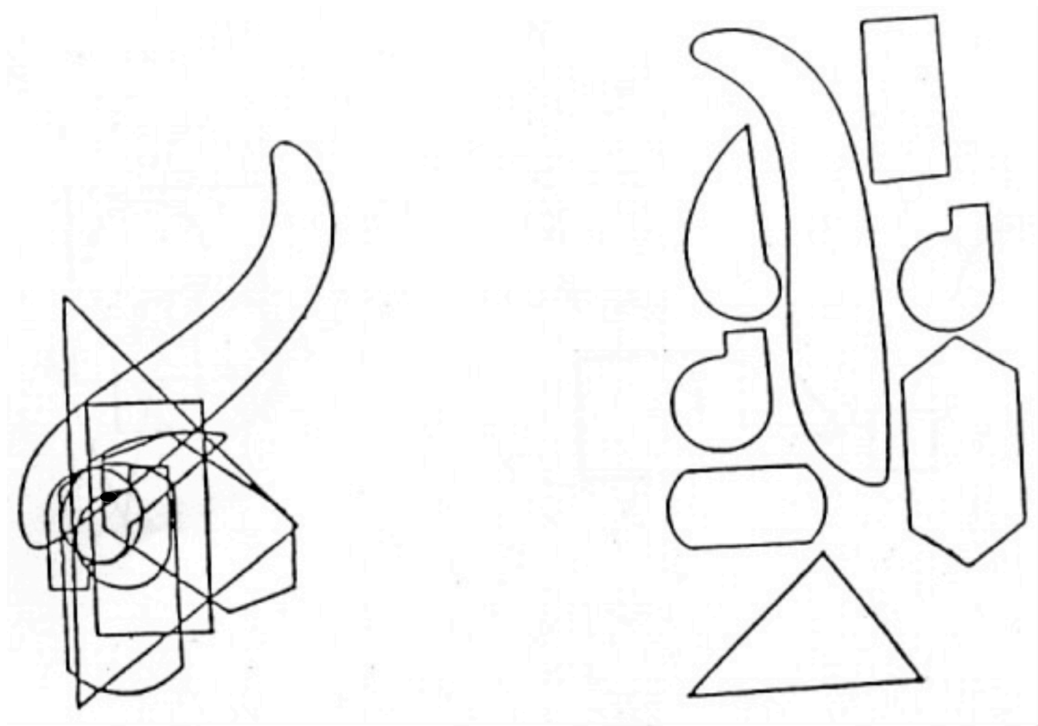
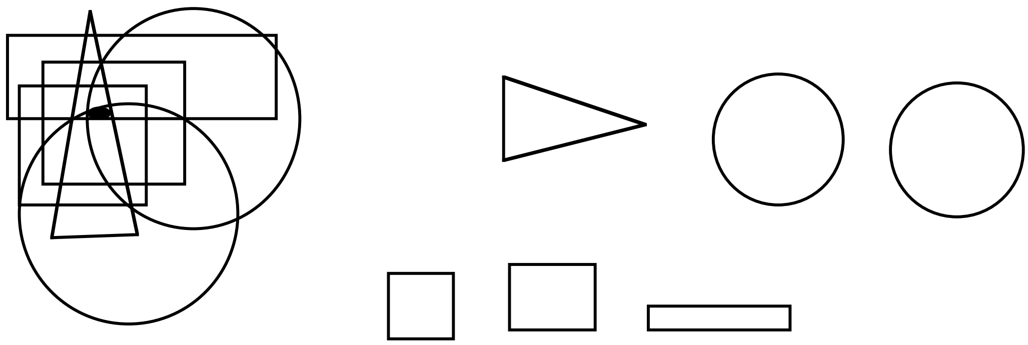
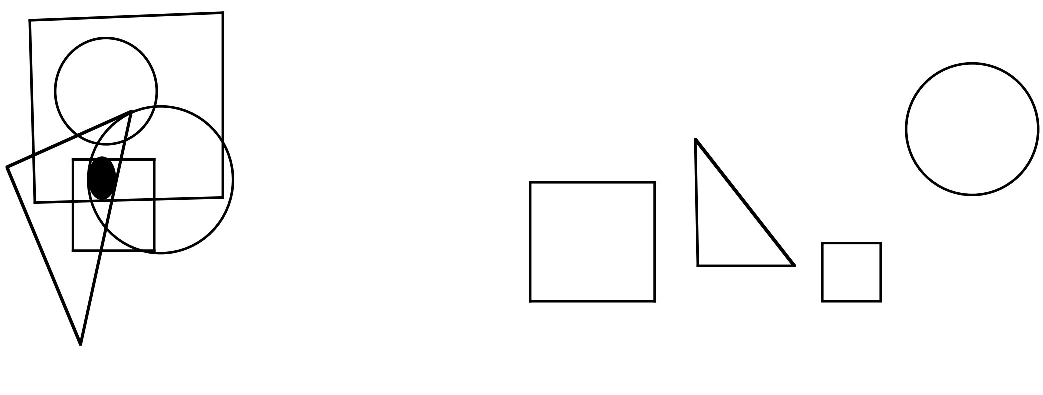
30	

31	 
32	 
33	 

34	
35	
36	

Appendix B

The group embedded figures test with answers

Shape Recognition within Complex Patterns

Name: __________ Sex: □ Boy □ Girl

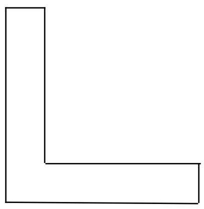
This is a test of your ability to find a simple shape when it is hidden within a complex pattern.

There are two examples to get you started.

The results will not affect your course assessment in any way.

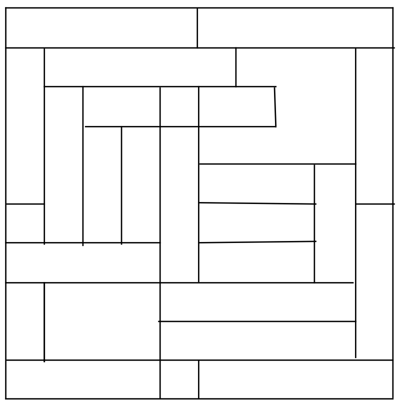
Example (1)

Here is a simple shape, which we have labelled (X):



(X)

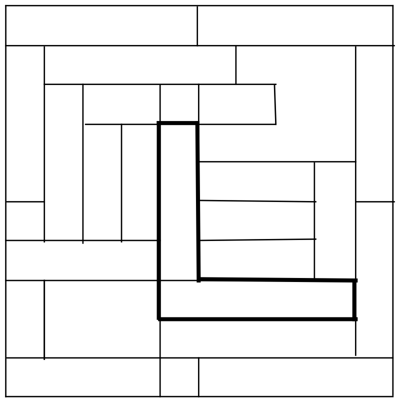
This simple shape is hidden within the more complex figure below:



Try to find the simple shape in the complex figure and trace it in pen directly over the lines of the complex figure. It is *the same size*, in *the same proportions*, *faces in the same direction*, and *appears only once* with the complex figures as when it appeared alone.

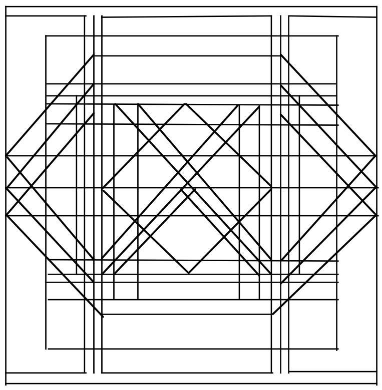
(When you finish, turn the page to check your answer.)

The answer is:

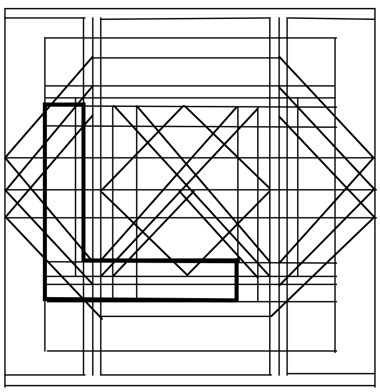


Example (2)

Find and trace the simple shape (X) in the complex figure beside it.

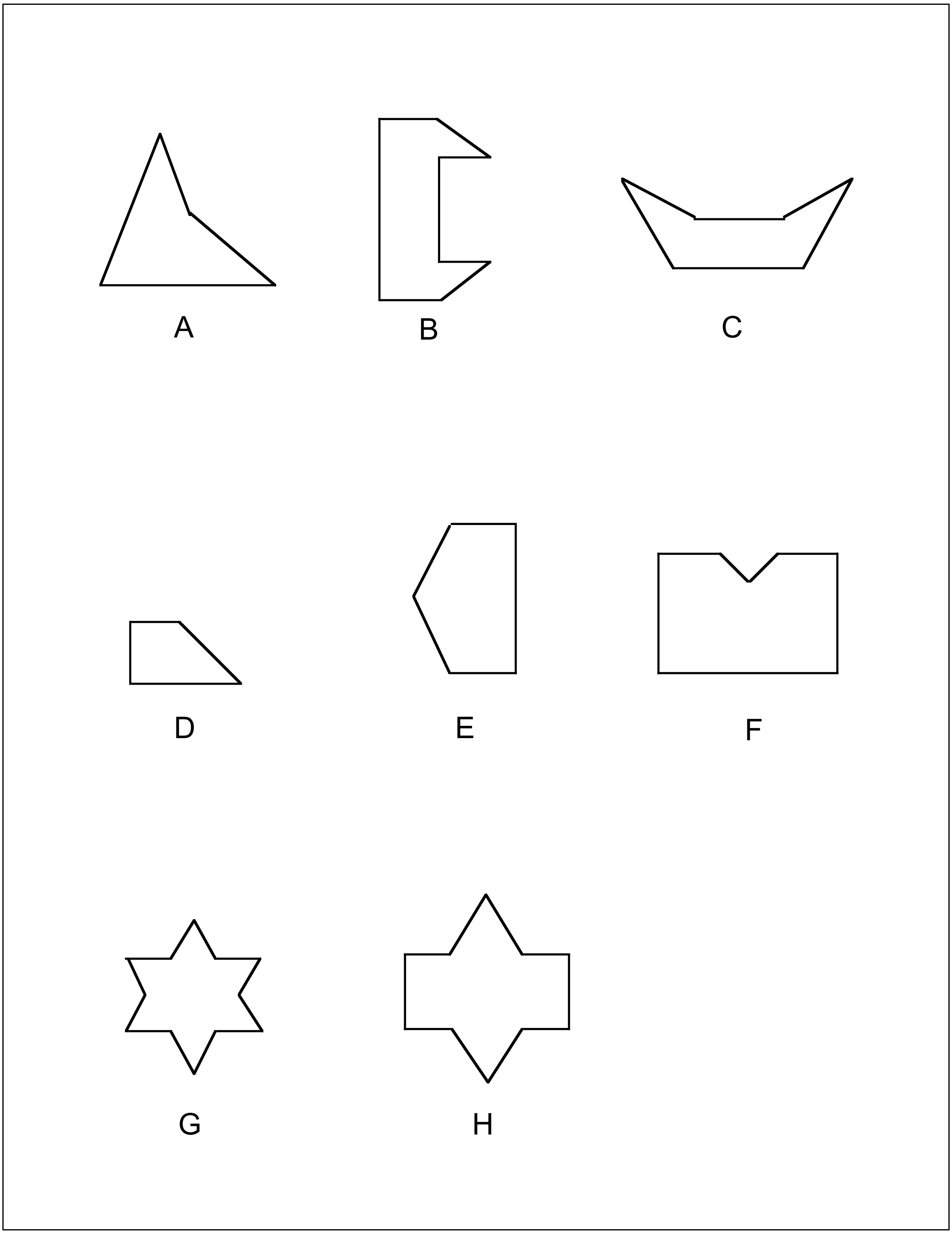


The answer is:

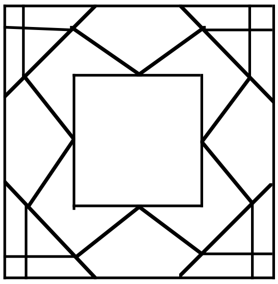


Now attempt each of the items on the following sheets:

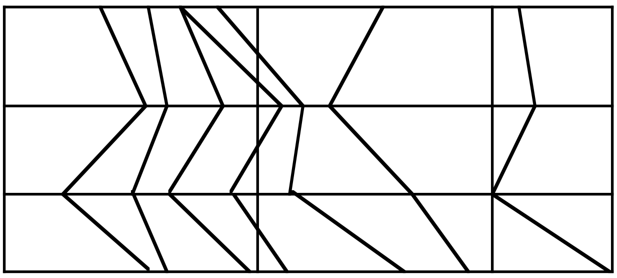
The shapes you have to find:



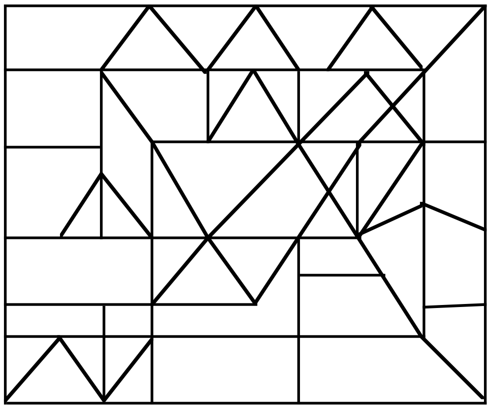
Look back at this simple forms as often as necessary!



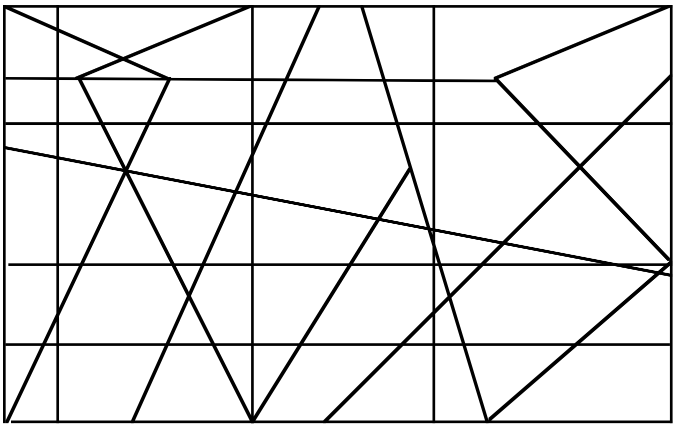
(1) Find shape B



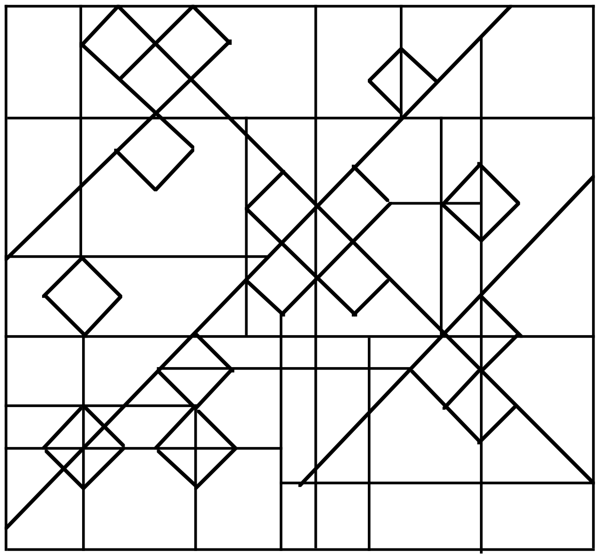
(2) Find shape D



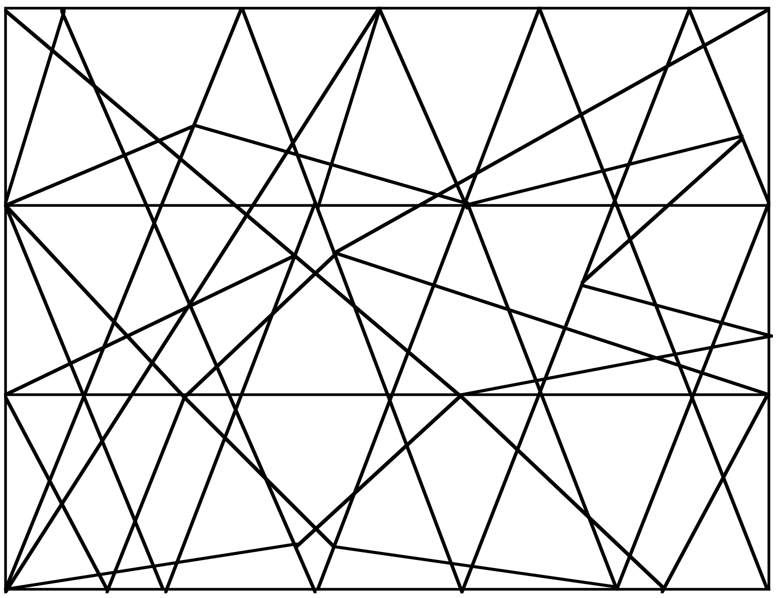
(3) Find shape H



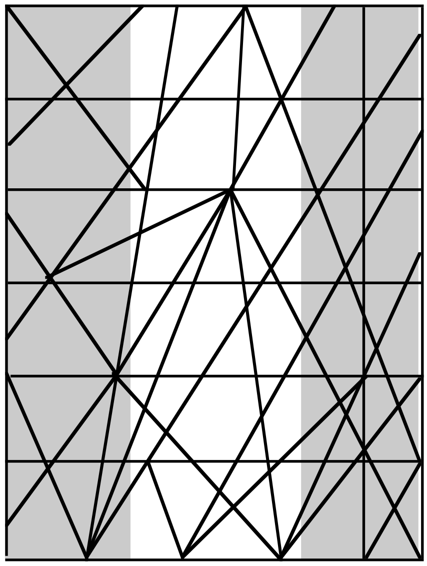
(4) Find shape E



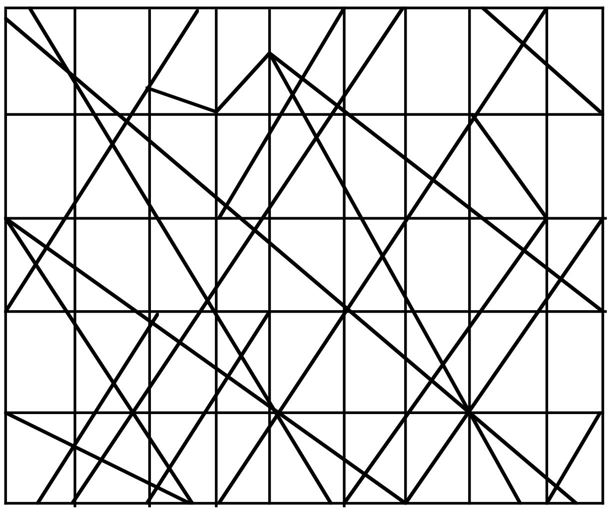
(5) Find shape F



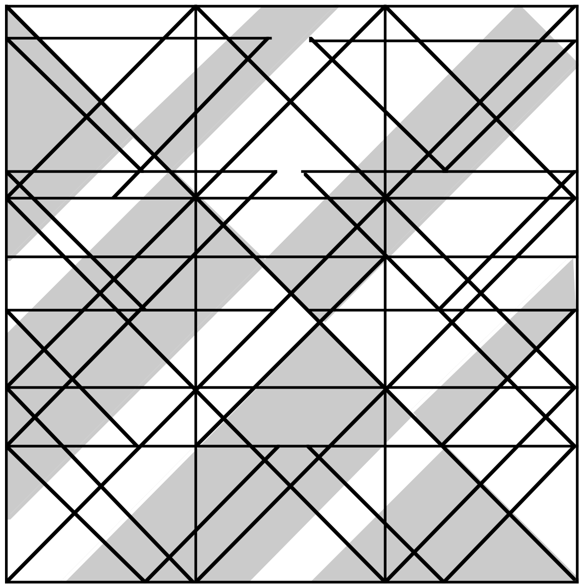
(6) Find shape A



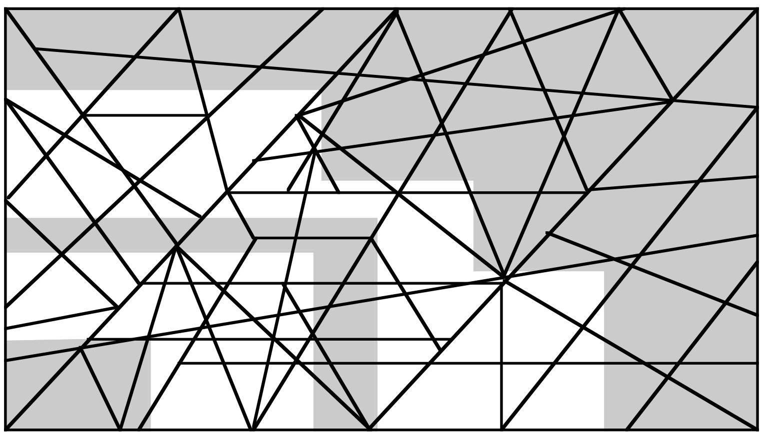
(7) Find shape E



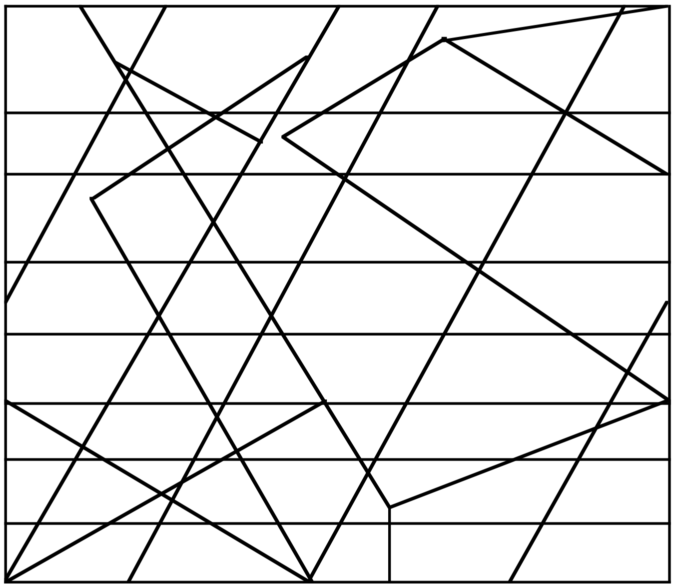
(8) Find shape H



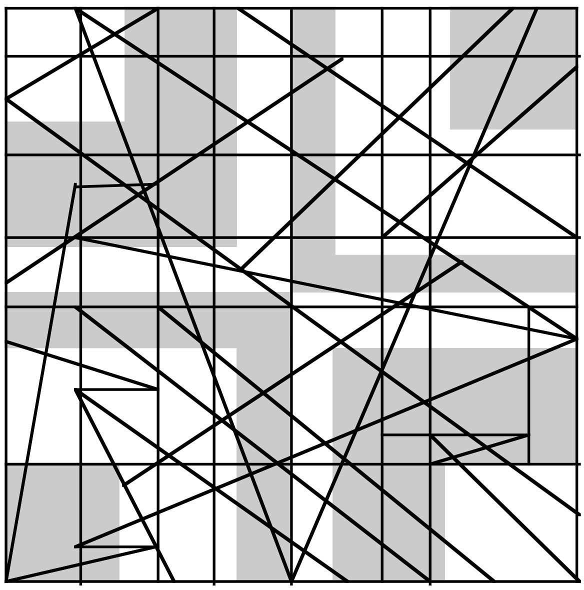
(9) Find shape D



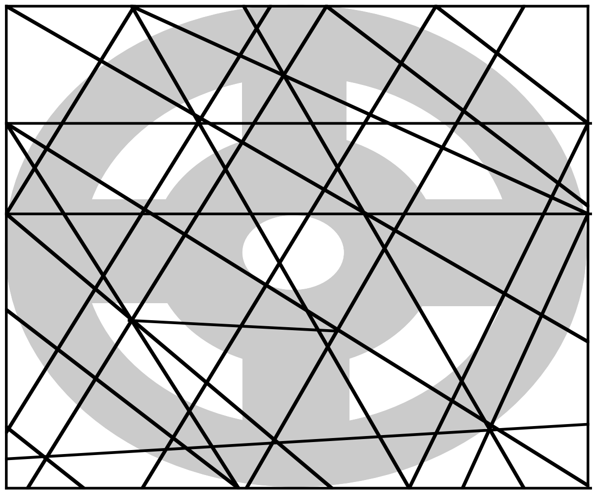
(10) Find shape G



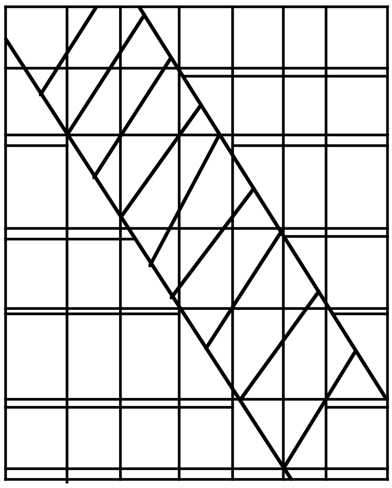
(11) Find shape C



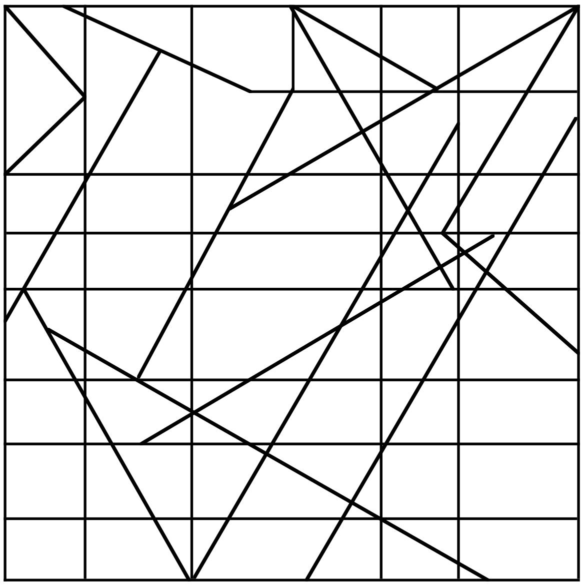
(12) Find shape B



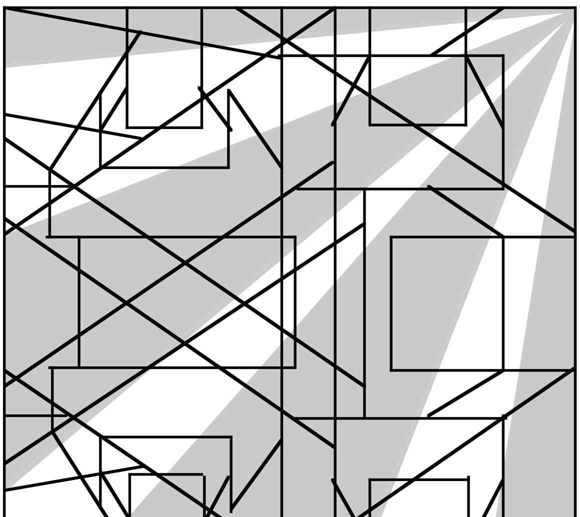
(13) Find shape G



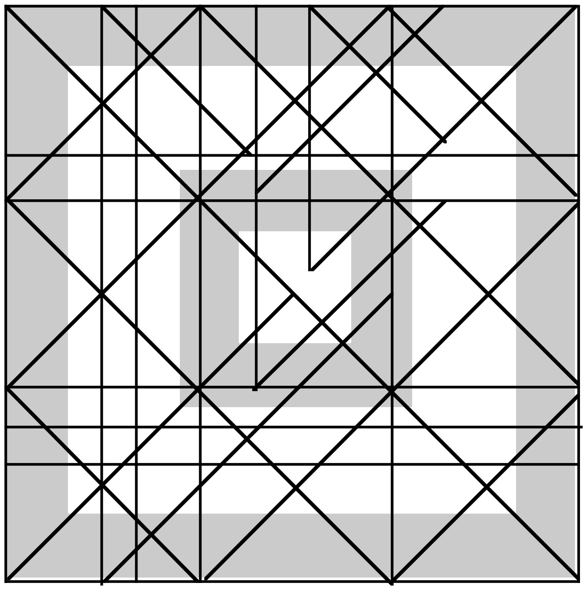
(14) Find shape H



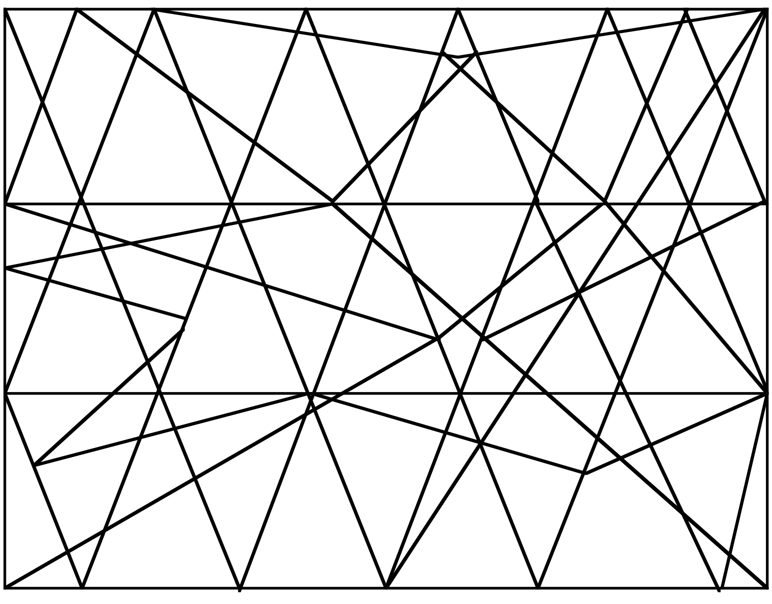
(15) Find shape C



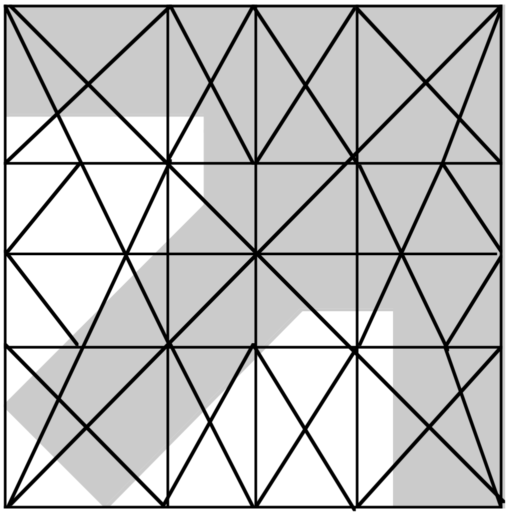
(16) Find shape B



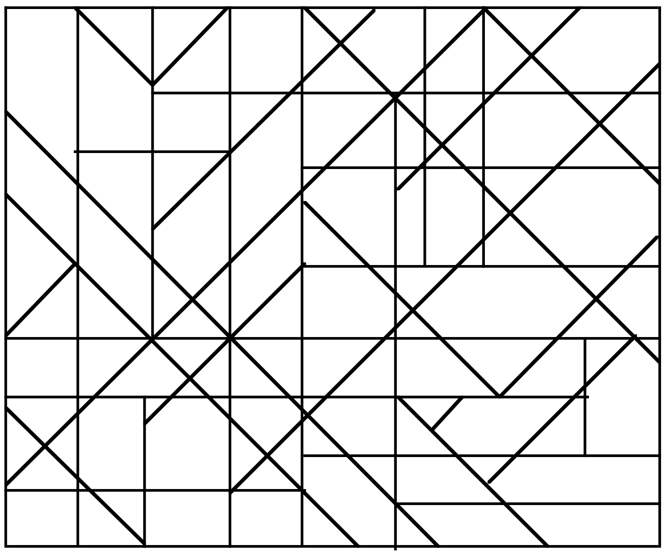
(17) Find shape D



(18) Find shape A

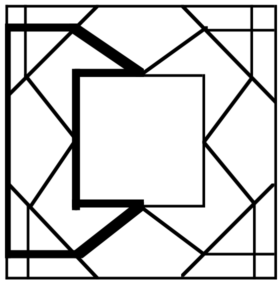


(19) Find shape E

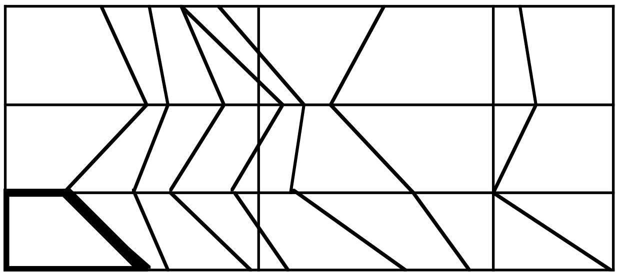


(20) Find shape F

The answers of shape recognition within complex patterns:



(1)



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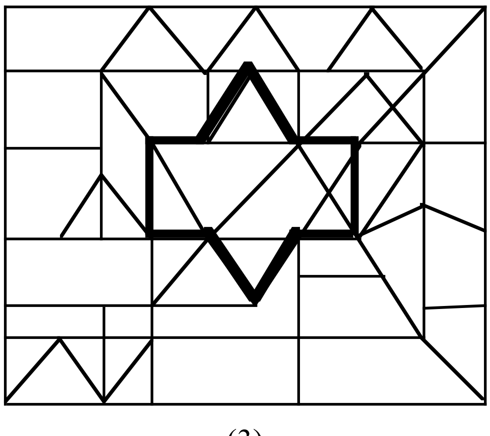

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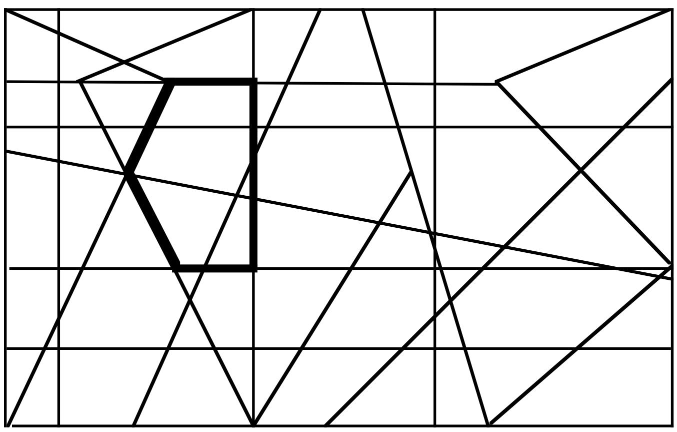

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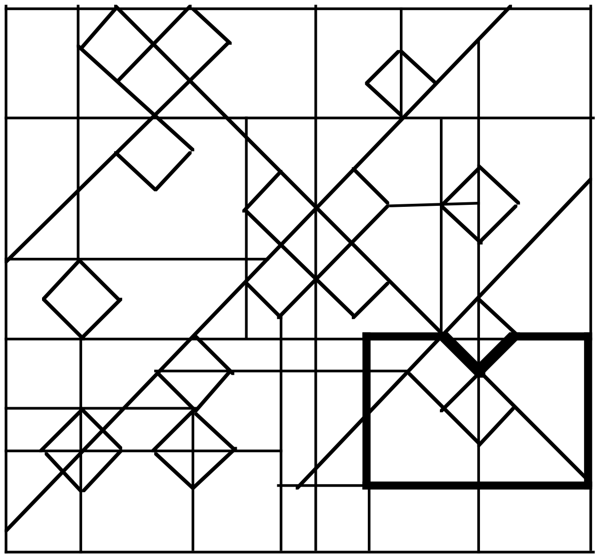

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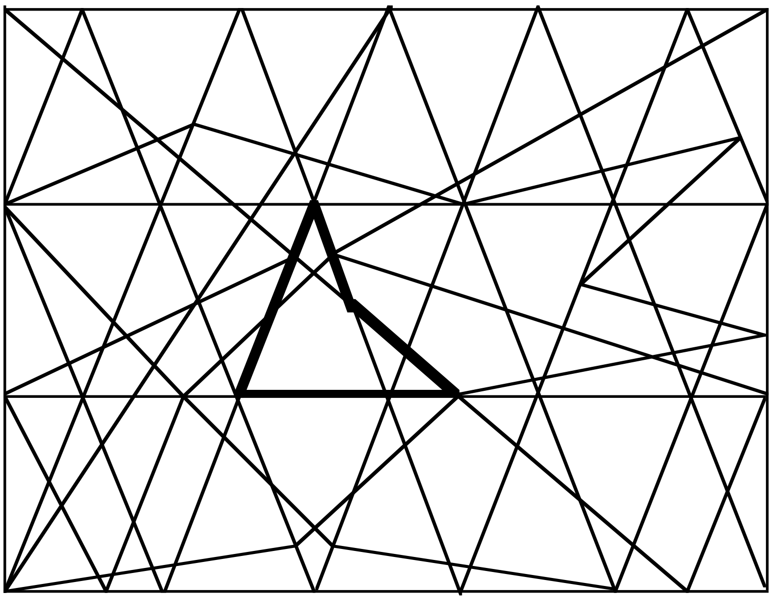

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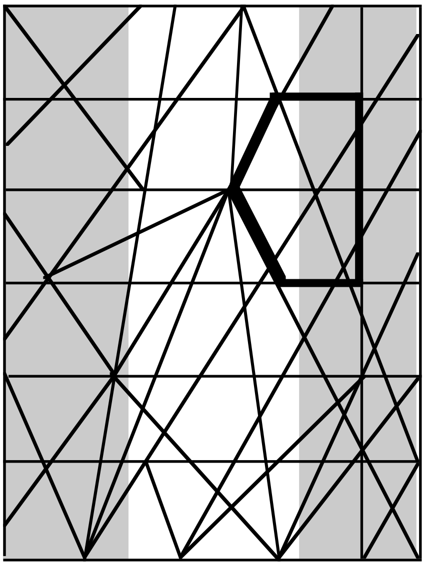

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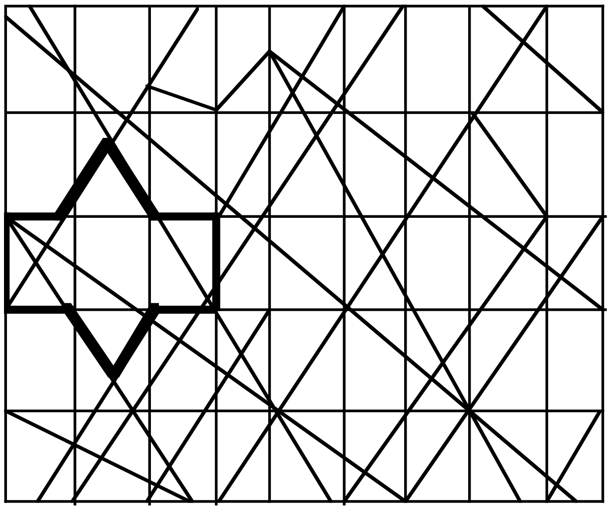

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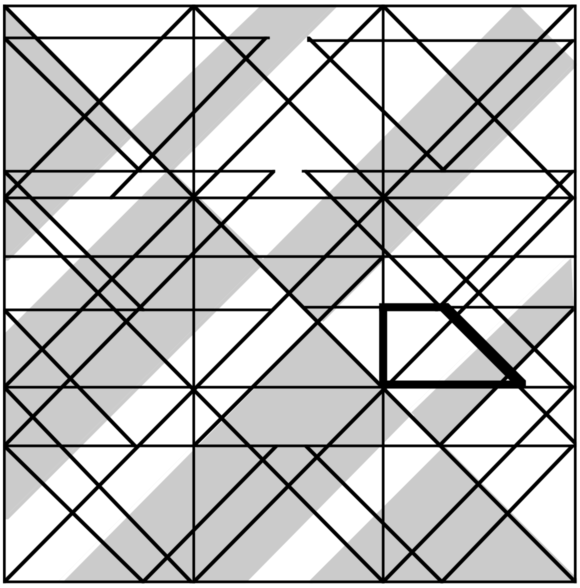

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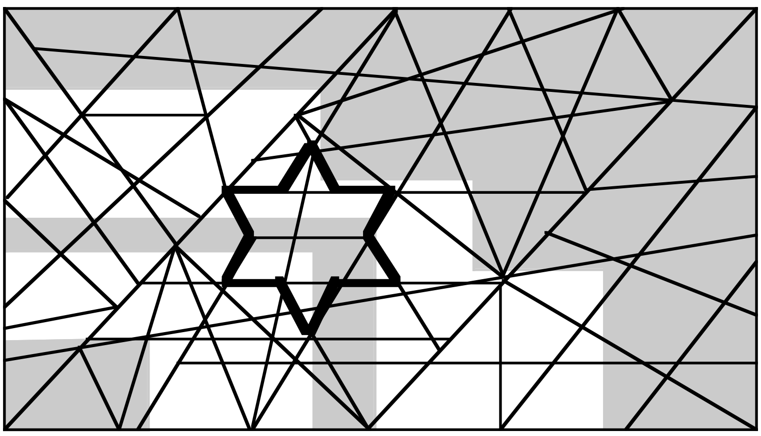

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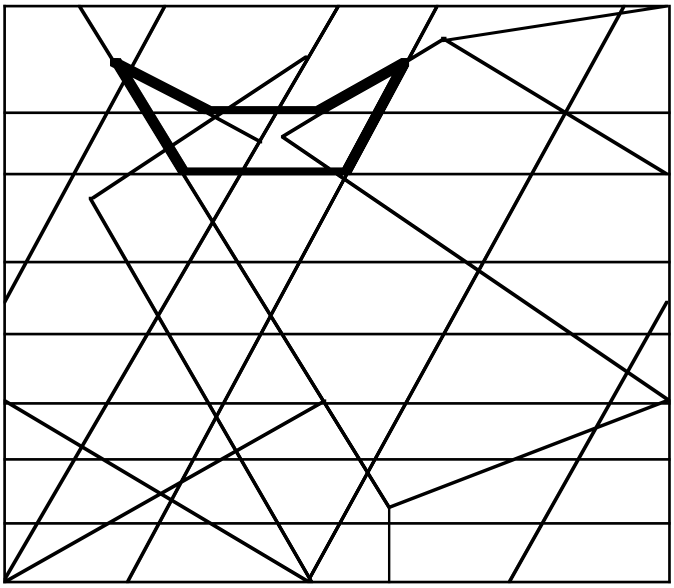

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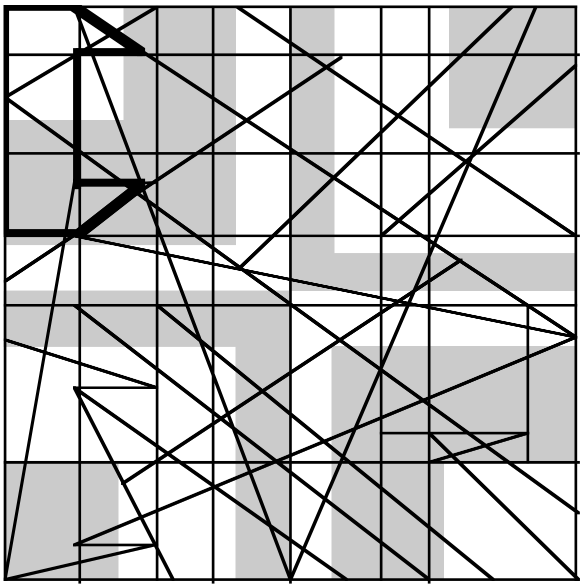

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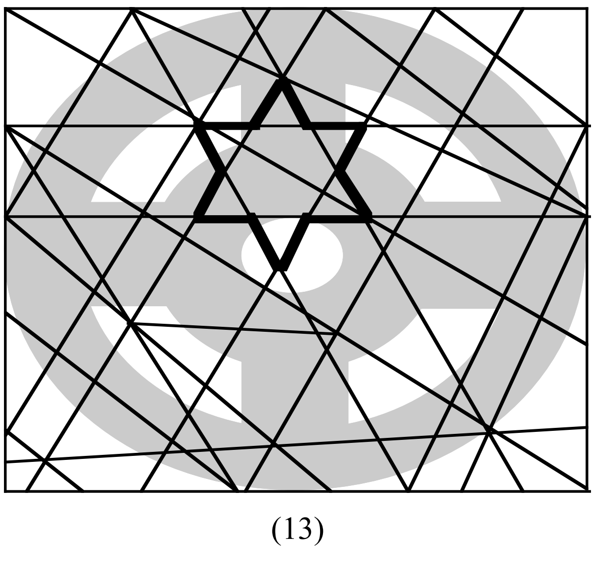

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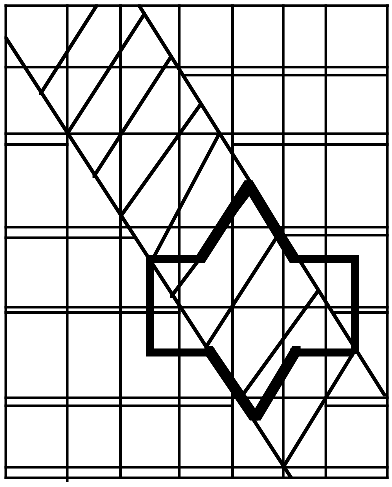

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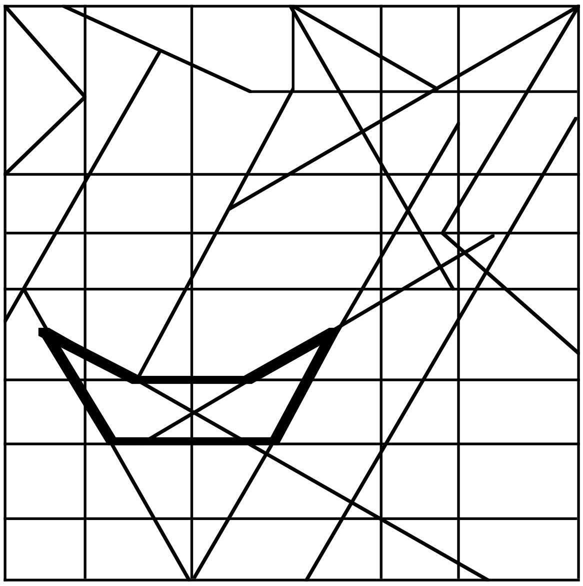

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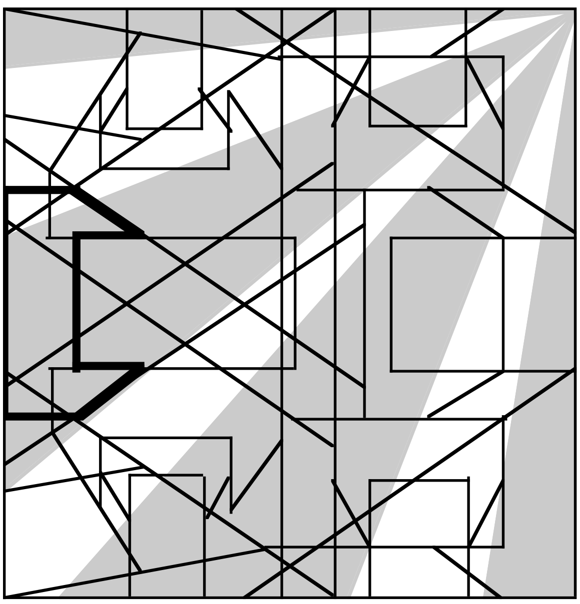

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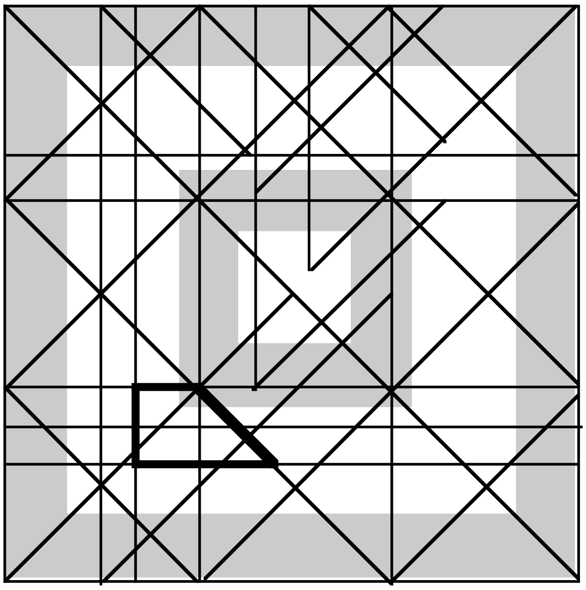

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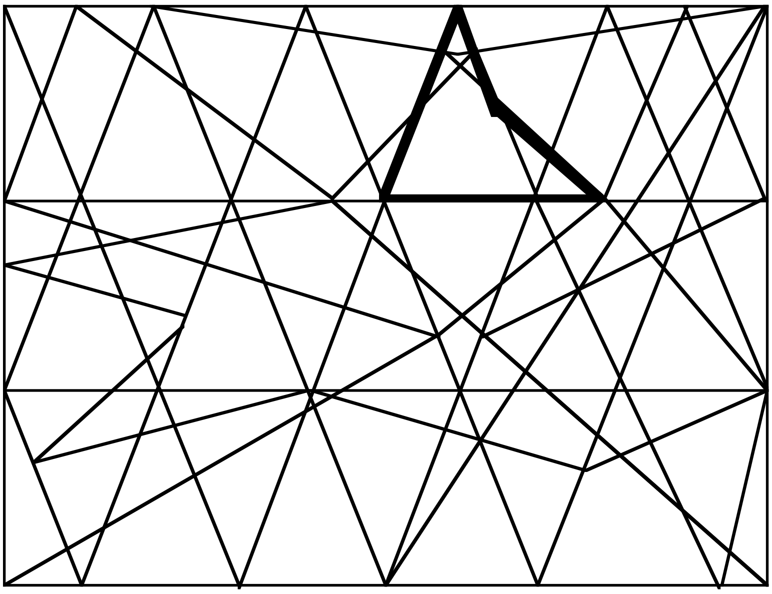

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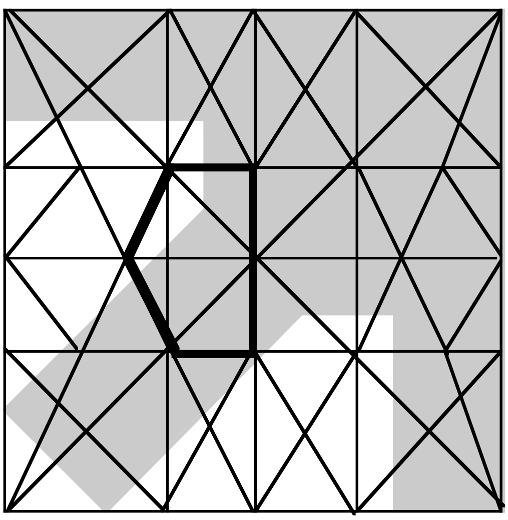

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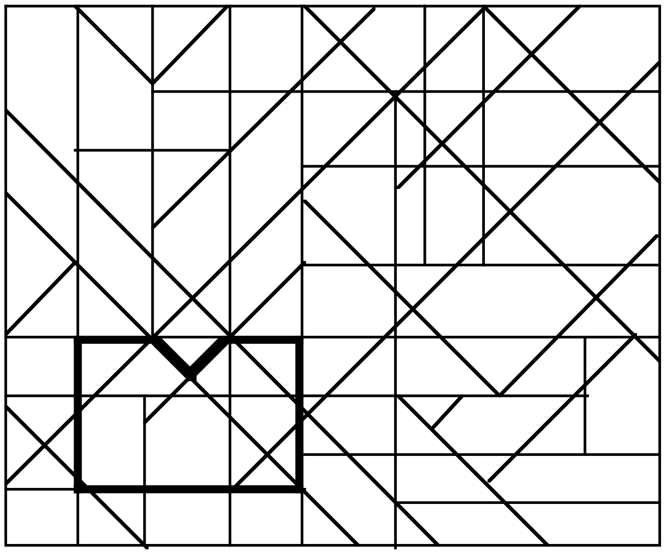

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Appendix C

Answers to the understanding test of genetics

Understanding Test of Genetics

Name: __________ Sex: □ Boy □ Girl

This is a test of your understanding about genetics.
There are four parts. Please follow the instructions to answer the questions.
The results of this test will not affect your schoolwork in any way.

Part 1: Comparing

(1) The six biological items in the list below are all parts of living system:

Cell	Chromosome	Gene	DNA	Organism	Nucleus

Now write the items in order of size in the boxes. Star with the smallest.

Smallest							Largest
	Gene	DNA	Chromosome	Nucleus	Cell	Organism	

(2) Please explain the relationships between two genetics terms below.

Gene / DNA: Genes are pieces of DNA.

DNA / Chromosome: Chromosome is one of the threadlike "packages" of DNA in the nucleus.

Gene / Organism: Genes control organism’s traits.

Part 2: Same or Different

The following tables are "comparing questions" between cells and cells within the individual, and between human and human. If the answer is same, please write "**S**"; if it is different, write "**D**".

Here is an example:

	Apple and Strawberry	Grape and Orange	Kiwi and Banana
The colour	**S**	**D**	**D**
The shape	**D**	**S**	**D**

(1) There are several kinds of cells which complete all structures and functions of a human being. According to your genetics knowledge, please compare the situations of genetic information between the following cells from the different parts of your body.

	Muscle cell and Muscle cell (in different parts of the body)	Muscle cell and Nerve cell	Muscle cell and Germ cell (sperm or egg)	Germ cell and Germ Cell (sperm or egg)
The number of chromosomes	S	S	D	S
The size of chromosomes	S	S	S	S
The number of genes	S	S	D	S
The type of genes	S	S	D	D

(2) In this world, some people look like you, but others don't. Please compare the following situations of the somatic cells between you (You are Taiwanese) and other people.

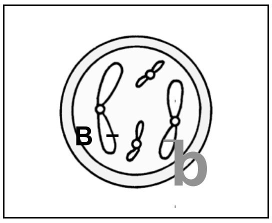
In the somatic cells	You and Scottish	You and Your father	You and Your mother	You and Your brother or sister	You and Your classmate (Taiwanese)
The number of chromosomes	S	S	S	S	S
The size of chromosomes	S	S	S	S	S
The number of genes	S	S	S	S	S
The type of genes	D	D	D	D	D

Part 3: You are a geneticist!

We know there are two kinds of eyelids in the Chinese population. One is single-edged eyelid, and the other is double-fold eyelid. The double eyelid versus the single eyelid is dominant that we use "B" to represent its gene.

(1) If a man and a woman are married and both of their eyelids are double-fold (the genotype is Bb).

In the following picture, one of the genes loci of the man's eyelids is marked (B). Please mark the other gene locus (b). (Here only shows two pairs of chromosomes of a human being.)



(2) Use Punnett square method to predict the possibility of their children's traits.

	1/2 B	1/2 b
1/2 B	1/4 BB	1/4 Bb
1/2 b	1/4 Bb	1/4 bb

Please explain the meaning of 1/2B that you write in the Punnett square.

- 1/2 means The probability of a child getting that gene
- B means A gene of the trait from father/mother, which is separated through meiosis

(3) Please answer the following questions in accordance with the results from Punnett square:

- Is it possible that the couple has a child with single-edged eyelids? yes (yes or no). The probability is 1/4.
- Is it possible that the couple has two children with single-edged eyelids? yes (yes or no). The probability is 1/16.
- Is it possible that all children's eyelids of the couple are double-fold and no single-edged? yes (yes or no). Why? The chances of every child to get his/her trait are the same. It is possible to get the same trait for all of the children.

Part 4: Give Mary a hand

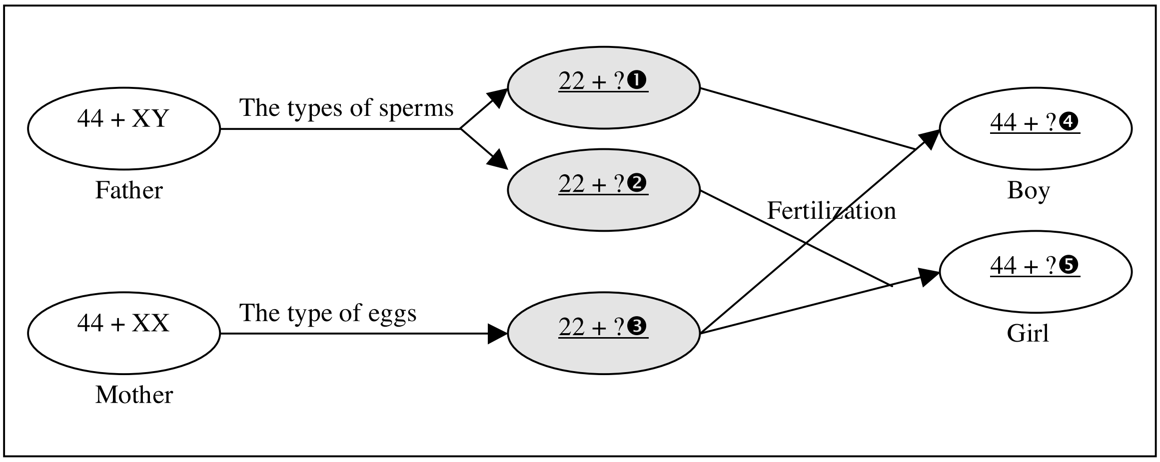
After genetics lecture, Mary has some questions about inheritance of human sex chromosomes which really confused her. Could you help her to solve these?

A Father	**B** Mother	**C** X
D Germ cells	**E** Somatic cells	**F** Y
G 0	**H** 50%	**I** 100%

There are some hints (nine boxes) to help you answering questions, which are labelled English letters from A to I on the upper left.

Please select the box(es) to answer the following questions - use English letters to show your answers and boxes may be used as many times as you wish.

1. Which cells do contain sex chromosomes? ---------------- D E
2. From whose X chromosome does Mary inherit? ------------- A B
3. If Mary has a brother, whose X chromosome dose he inherit? --- B
4. There are two daughters in Mary's family. If Mary's mother wants a son, what is the possibility she can get that? --------------- H
5. If Mary's mother had the double-fold eyelids surgery, what is the possibility that the next son get this trait from her? (The trait of double-fold eyelids is dominant) ------------------------ G
6. The following figure indicates human chromosomes' arrangement to determine the gender of next generation and keep the numbers of chromosomes of next generation constant. Please complete these question marks in the figure using the boxes above.
   ❶ F
   ❷ C
   ❸ C
   ❹ C F
   ❺ C C



Appendix D

The teaching material of genetics

Genetics

Teacher's Guide

This teaching material makes up a set of lessons developed for the genetics course first year of junior high school in Taiwan. The main aim of this material is not only to teach basic ideas about genetics but to encourage the students to apply their ideas to real life situations. This will lead to a greater appreciation of the importance of works in genetics in our society today and in the future.

At the end of the course, the student is expected to:

(a) Know the basic terminology related to genetics;
(b) Understand the ideas of Mendel;
(c) Know how to use a Punnett square to predict the phenotype of offspring;
(c) Understand traits and human inheritance
(d) Understand how sex is determined in offspring;
(e) Appreciate the nature and role of genetic counseling and genetic engineering;
(f) Understand some of the issues affecting decisions arising from genetics developments.

By experiencing different views of the same issue, students are encouraged to recognize the many facets of real-life decision taking and to accept that decisions often have to be made on the basis of incomplete information. Students will also have opportunities to assess data presented in several forms, to weigh arguments, to contribute meaningfully to a group discussion, to process self-studying and self-thinking from problem solving, to develop own attitude and idea by multimedia help, to present arguments based on gathered evidence and to listen to the arguments proposed by others. They should begin to see the importance of genetics ideas in the context of their lives.

How the Sequence of Lesson Take Place

It is important that the students are allowed to interact in groups (sometimes as individuals) with the materials. The role of the teacher is sometimes that of **manager** rather than **teacher**. Allow pupils to discuss and do not intervene in groups unless a group becomes hopelessly lost.

The lessons are presented under five themes:

(1)	Basic terminology	1 lesson
(2)	Theory of Heredity	2 lessons
(3)	Human Inheritance	2 lesson
(4)	Sex Determination	1 lesson
(5)	Genetics in Our lives	2 lessons

Lessons are planned in the following way.
Please follow the procedure described overleaf.

(1) Basic terminology

(a) Divide the class into groups of 6. An occasional 7 is possible. Allow the groups to sit around a convenient bench or table.
(b) Select a leader for each group.
(c) To each group, give sheet 1 to pupi1, sheet 2 to pupil 2 and so on, sheet 6 to the leader. Where there is a group of 7, give two pupils sheet 3.
(d) Allow the pupils 20-25 minutes for group discussion
(e) Re-form the class and give out the test. Allow enough time for pupils to complete the test (about5-8 minutes).

(2) Theory of Heredity

Lesson 1

(a) Form groups of four and give each pupil the papers entitled Theory of Heredity-Mendelism (1).
(b) There are four spaces to be completed - each group member should do one, filling in the group's agreed conclusions.
(c) Do the questions in turn controlled by the teacher. Don't turn to the next page before the question is done.

Lesson 2

(a) Give each pupil the papers entitled Theory of Heredity-Mendelism (2).
(b) Pupils attempt to complete the questions on their own, after about 25 minutes, students should compare answers and help each other as necessary.

(3) Human Inheritance

Lesson 1

(a) Form groups of four and give each pupil the papers entitled Gamete Combination.
(b) Allow the groups to work through the exercises for the whole lesson.

Lesson 2

(a) Give each student the sheets entitled "Comparing with Each Other".
(b) Allow them to work in pairs to complete their own individual traits.
(c) The last part is a class exercise. Take the class through this, following the instructions on the last page.

(4) Sex Determination

(a) Give out the sheets entitled "Sex Determination".
(b) This is an individual exercise - allow pupils to work on their own.

(5) Genetics in Our lives

Lesson 1

(a) Take students to the computer room.
(b) Give each student the sheet entitled, "Genetics in Our Lives"
(c) Allow students to follow the instructions, finding the web sites and completing the answers to questions.

Lesson 2

(a) Form groups of three pupils and allow them to sit around a desk.
(b) Give each group a set of reading information for further discussion.
(c) Give each students a copy of the sheet entitled, "Cloning Humans - Right or Wrong?"
(d) Allow pupils abut 30 minutes to discuss the questions and write down their agreed answers.
(e) After the group work, ask how many groups favoured human cloning and how many were against it.
(f) Select some groups and ask them for the most powerful reasons they had for or against it.
(g) If time allows, let the students start the exercise, "Homework". This can be completed at home.

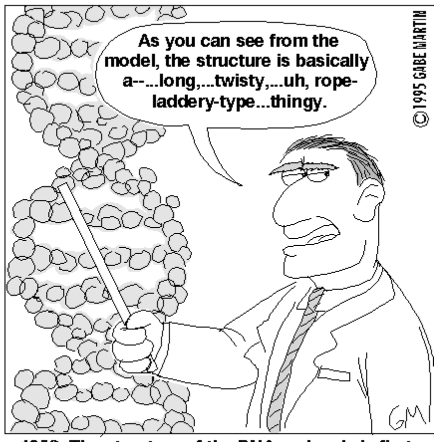
(1) What is DNA?

Let's examine a group of cells in your inner ear. They help support the function of hearing.

How do these cells "know" that their role is to support hearing instead of something else, like making your heart beat?

Instructions providing all of the information necessary for a living organism to grow and live reside in the nucleus of every cell.

These instructions tell the cell what role it will play in your body.



1953: The structure of the DNA molecule is first described.

What do these instructions look like?

The instructions come in the form of a molecule called DNA; deoxyribonucleic acid. DNA encodes a detailed set of plans, like a blueprint, for building different parts of the cell.

How can a molecular hold information?

The DNA molecule comes in the form of a twisted ladder shape scientists call a "double helix." The ladder's rungs are built with the four-letter DNA alphabet: A, C, T, and G. these alphabet pieces join together according to special rules. A always pairs with T, and C always pairs with G.

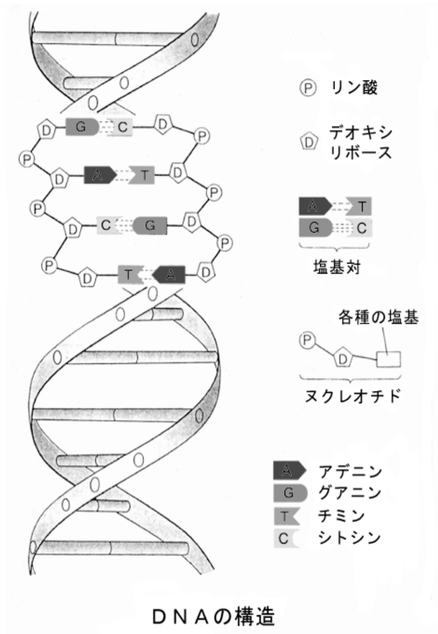
How can only four letters tell the cell what to do?

For example:

The DNA strand is made of letters:
ATGCTCGAATAAATGTCAATTTGA

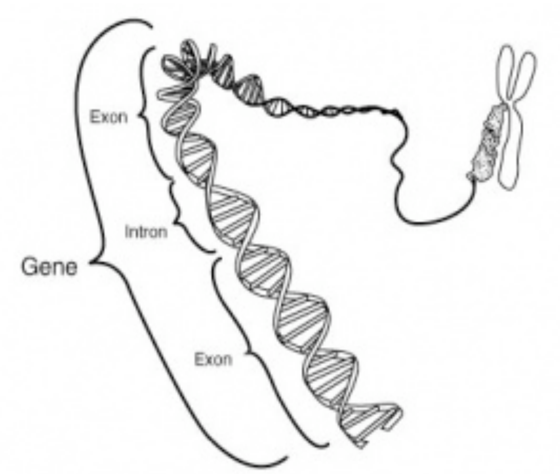
The letters make words:
ATG CTC GAA TAA ATG TCA ATT TGA

The words make sentences:
<ATG CTC GAA TAA> <ATG TCA ATT TGA>



These "sentences" are called genes. Genes tell the cell to make other molecule called proteins. Proteins enable a cell to perform special functions, such as working with other groups of cells to make hearing possible.

(2) What is a gene?



Genes are instruction manuals for our bodies. They are the directions for building all the proteins that make our bodies function.

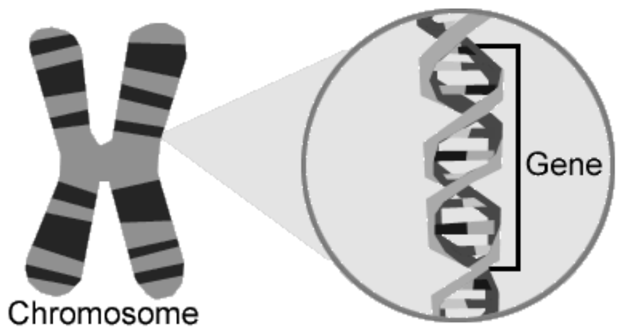
Genes are made of DNA. One strand of our DNA contains many genes. All of these genes are needs to give instructions for how to make and operate all parts of our bodies.

For example, blood contains red blood cells that transport oxygen around our bodies. The cells use a protein called “haemoglobin” to capture and carry the oxygen.

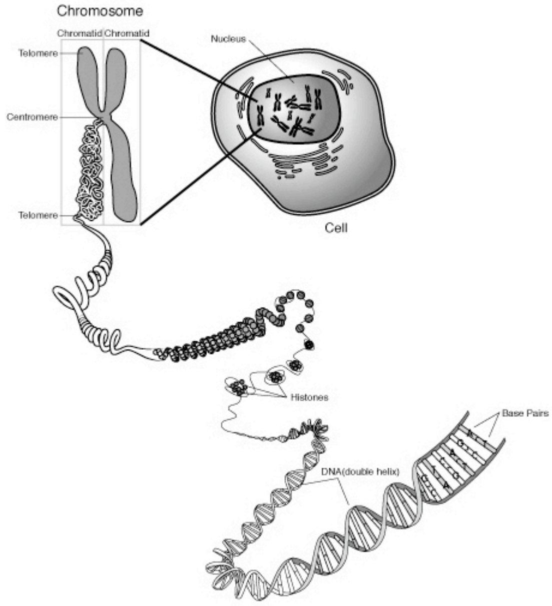
Of over 25000 genes, only a few contain the instructions for making haemoglobin proteins. The remaining genes contain the instructions for making other parts of our bodies.

If our haemoglobin gene is normal, the haemoglobin protein works fine. But if the instructions in that gene are changed, or “mutated,” changes in the haemoglobin protein could result. One such mutation causes a disorder called sickle cell anemia.

Genes contain instructions for building proteins, which are involved in all sorts of things. Haemoglobin protein is just one example. Other proteins such as the enzymes that produce pigment in your eyes and keran, responsible for growing hair and nails, are also produced by genes.



(3) What is a chromosome?



Each cell in our body contains a lot of DNA. In fact, if you pulled the DNA from a single human cell and stretched it out, it would be three meters long!

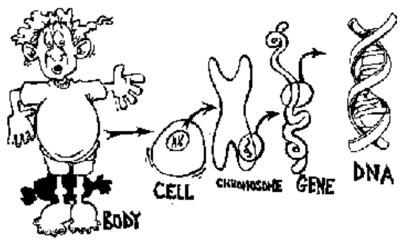
That's about as long as a car!

How does all of the DNA into a cell?

The DNA is packaged into compact units called "chromosome."

The packaging of DNA into a chromosome is done in several steps, starting with the double helix of DNA. Then the DNA is wrapped around some proteins.

These proteins are packed tightly together until they form a chromosome. Chromosomes are efficient storage units for DNA.



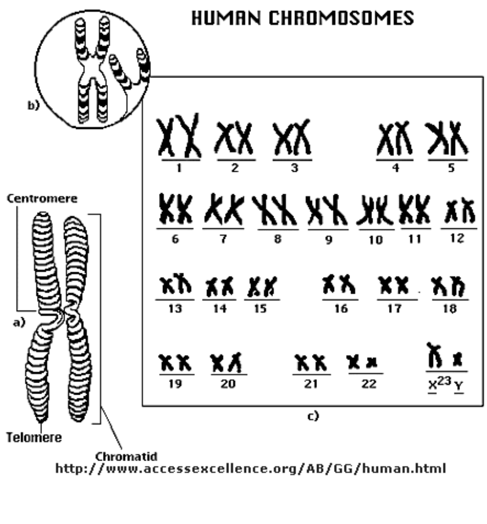
How many chromosomes does one cell hold?

The correct answer to this depends on whether you are a fish or a fly, or a human.

Each human call has 46 chromosomes. All the DNA is organized into two sets of 23 chromosomes. We get genetic material from both of our parents – that's why children look like both their mum and dad.

Not all living things have 46 chromosomes, like human. Mosquitoes, for instance, have 6. Onions have 16. Carp have 104.

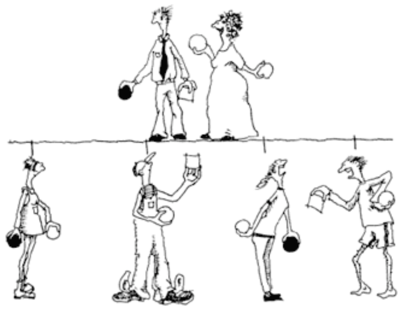
What can we learn from looking at our chromosomes?



Look at this set of chromosome. You can see that matching chromosomes have been lined up in pairs – one each from mum and dad. Although the DNA double helix is too small to see, chromosomes can be viewed with a microscope, as in this picture.

There are two sex chromosomes that determine whether you are male or female. In the picture the sex chromosomes are labelled "X" and "Y". The set of chromosome in this picture are from a male – you can tell because female do not have a Y chromosome. Instead, they have two X chromosomes.

(4) What is heredity?



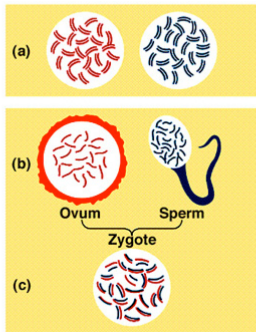
Why do children look like their parents? Why do brothers and sisters resemble each other?

This is because we “inherent” traits from our parents. The passing of traits from parents to child is the basis of heredity.

Where exactly are our traits?

Our genes encode the instructions that define our traits. Each of us has thousands of genes, which are made of DNA and reside in our chromosomes.

The environment we grow up and live in also helps define our traits. For example, while a person’s genes may specify a certain hair colour, exposure to chemicals or sunlight can change that colour.



How do we get traits from our parents?

Human have two complete sets of 23 chromosomes (2x23=46 total).

When parents conceive a child, they each contribute one complete set to the child. In this way, parents pass genes to the child. Every child receives half of its chromosomes from the mother and half from the father. This transfer takes place at conception, when the father’s sperm cell joins with the mother’s egg cell.

While most cells in our bodies contain two sets of chromosomes (2x23=46), sperm and egg cells each have only one set (23). When they join, they create a single cell called a “zygote”, which has two sets of chromosomes (46).

This cell will divide, ultimately developing into a child.

Each parent contributes one complete set of chromosomes to the child. This set can contain chromosomes from both of the parent’s two sets. The only rule is that the child must receive exactly one of each chromosome.

Since the parents contribute chromosomes randomly to each new child, every child inherits unique set of chromosomes. As a result, every child will have a unique combination of traits. Some will resemble the mother, and some will resemble the father. Still others will be unique, a product of the new combination of chromosomes.

Squares mean chromosomes combination

Dad	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23

Mom	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23

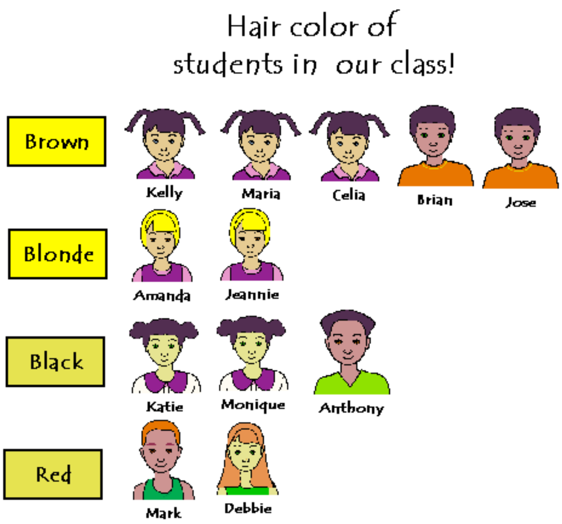
Child 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23

Child 2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23

(5) What is a trait?

A trait is a notable feature or quality in a person. Each of us has a different combination of traits that make us unique.

Traits are passed from generation to generation. We inherit traits from our parents, and we pass them on to our children.



What types of traits exist?

Physical traits are characteristics of one's physical makeup. These include hair colour, eye colour, and height.

Behavioural traits are characteristics of the way one acts. A sheepdog's herding instinct and a retriever's desire to fetch are good example of behavioural traits.

Predisposition to a medical condition. An increased risk of getting a certain type of disease is also a type of trait that can be passed from parent to child. Some examples of such diseases include sickle cell anemia, cystic fibrosis, heart disease, cancer, and certain types of mental illness.

What defines our traits?

The instructions encoded in our genes play a role in defining traits. But the non-genetic, or "environmental," influences in our lives are just as important in shaping our traits. Sometimes these environmental factors can even change a trait!

Let's see some example.

Physical traits
Genetics: Our genes determine our natural hair colour
Environment: Exposure to sun or hair dyes can easily change that colour.

Behavioural traits
Genetics: People breed retrievers to chase things and bring them back.
Environment: You can train a retriever to instead roll over and "play dead" when you toss a ball.

Predisposition to a medical condition
Genetics: A person may be born with an increased risk of heart disease.
Environment: Eating health foods and exercising can reduce this risk.

(6) Questions

Instructions

Allow the other five members of your group time to read their sheets.
While they are doing that, read through this sheet.

Your task is to ask each question and one member of your group will have the answer on their sheet. If no answer comes, the sheet number where the answer is to be found is given. Try to encourage that member of your group to give the answer.

Make sure that the answer to each question is understood by the whole group.

Then move on to the next question.

Questions:

(a) What tells a cell what role it will play in your body, like a blue print for a building? (1)

(b) Where is DNA? (1, 3)

(c) What does DNA look like? (1)

(d) Where is chromosome? (3)

(e) How many chromosomes does one cell hold? (3)

(f) What is the relationship between DNA and chromosome? (3, 4)

(g) How can DNA hold information? (1)

(h) What is the relationship between DNA and gene? (1, 2)

(i) What are the functions of gene? (2)

(j) What is a trait? (4, 5)

(k) What types of traits exist? (5)

(l) What is the relationship between gene and trait? (5)

(m) Are traits only influenced by gene? (5)

(n) Why do children look like their parents? (3, 4)

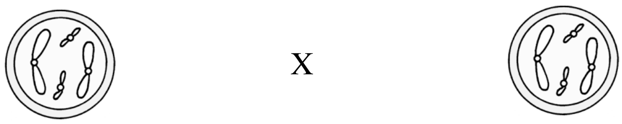
(o) How do we get traits from our parents? (3, 4)

Test

***Class:* __________ *Number:* __________ *Name:* __________**

(1) Please draw a picture about “the relationships among Cell, DNA, Gene, Chromosome, and Nucleus”, and than describe.

(2) If there is an organism, which has four chromosomes; two pairs (as the following pictures), please draw a picture and describe how children look like their parents on the chromosome level?



Theory of Heredity - Mendelism (1)

From its parents an individual inherits the characteristics of the species. These are called ***traits*** and include things like hair colour, blood type and facial appearance.

In sexual reproduction, a new individual is derived only from the ***gametes*** (sex cells) of its parents. The hereditary information is passed on in ***genes***. Genes are contained in the nucleus of the gametes and located on the ***chromosomes***.

(1) If a pure-breeding black mouse is mated with a pure-breeding brown mouse, the offspring will not be intermediate colour, i.e. dark brown or some combination of brown and black, but will all be black (See Figure 1).

Q: From your previous work on gamete formation and fertilization, can you explain what happened on the genes between parents ***(P)*** and the first filial generation ***(F1)***?

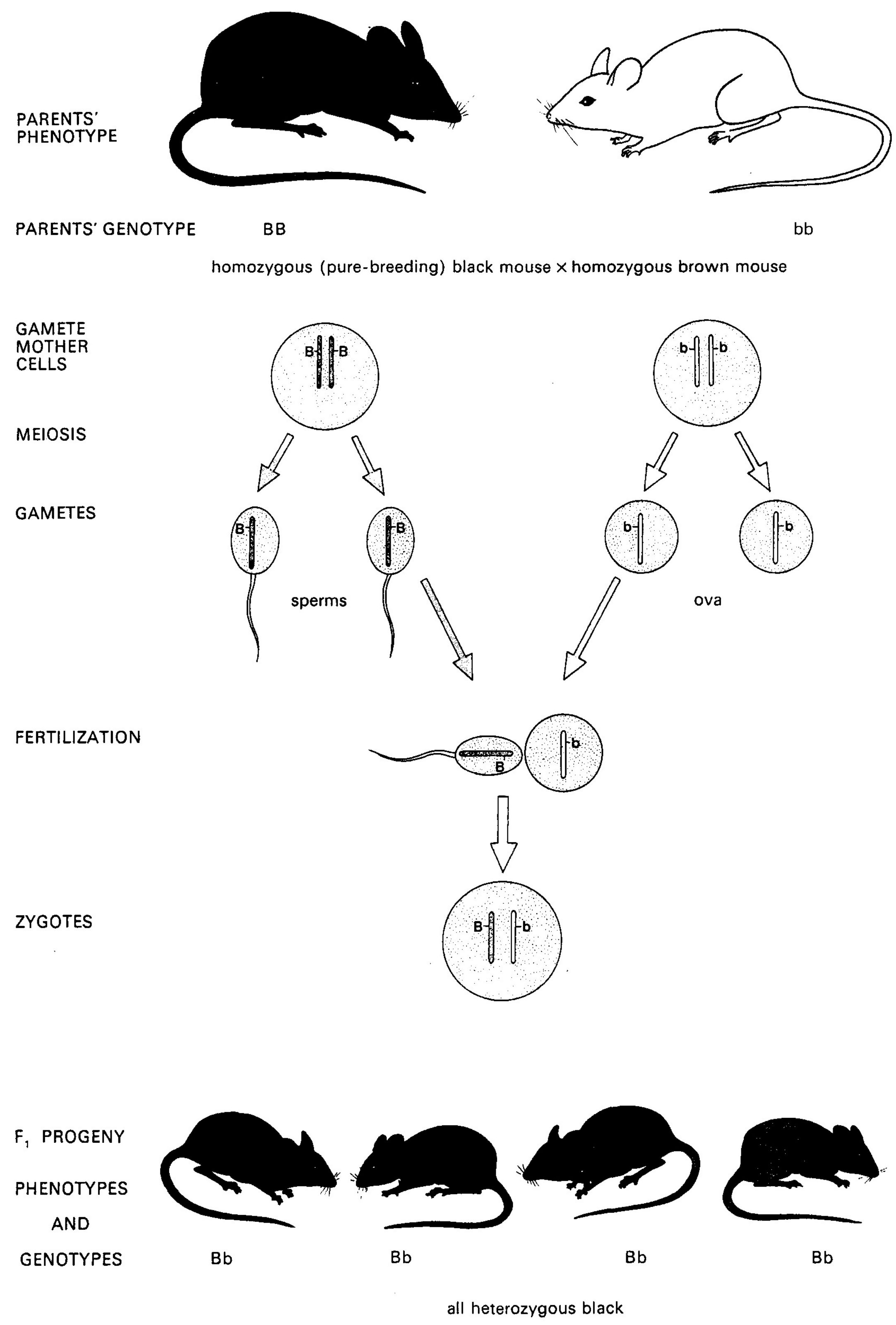

PARENTS' PHENOTYPE
PARENTS' GENOTYPE
BB
bb
homozygous (pure-breeding) black mouse × homozygous brown mouse
GAMETE MOTHER CELLS
B B
b b
MEIOSIS
GAMETES
B
B
b
b
sperms
ova
FERTILIZATION
B
b
ZYGOTES
B b
F1 PROGENY
PHENOTYPES
AND
GENOTYPES
Bb
Bb
Bb
Bb
all heterozygous black

Figure 1

(2) The gene for black fur is said to be ***dominant*** to that for brown fur, because although each of the baby mice, being the product of fusion of sperm and egg, must carry genes for both blackness and brownness, only that for blackness is expressed in the visible characteristics of the animal. The gene for brown fur is said to be ***recessive***. A physical characteristic is known as a ***phenotype***.

In explanation, it will be assumed that a pure-breeding black mouse carries a pair of genes controlling the production of black pigment. The genes are represented on the figure 1 by the letters **BB**, which is called ***genotype***, and the capital letters signify dominance. The brown mice carry the genes **bb**, which signify recessive.

Q: In the box below, explain in your own words how the genotype of the baby mice arises, with parents which are BB and bb.

Q: Why is the colour of baby mice black like the colour of their father, but genotype Bb is different from the father's genotype BB?

(3) The genes B and b influence the same characteristic, namely coat colour, but in different ways. Two genes (BB, Bb, or bb) must be present in the baby mice, because the individual receives one chromosome from each parent. During the formation of gametes, the process of meiosis will separate the pair of chromosomes, so that the gamete (sex cell) will contain only one gene from each pair. All the sperms from the pure-breeding black parent will carry the gene B and all the eggs from the brown parent will carry the gene b. When the gametes fuse, the zygotes will contain both genes B and b, but since B is dominant to b, only the former gene is expressed (this means will be shown). Thus, the offspring will all be black.

(4) If, when the baby mice are mature, these F1 black are mated amongst themselves, their offspring, the F2, will include both black and brown mice, and if the total number for all the F2 families are added up, the ratio of black to brown babies will be approximately 3 to 1. (See Figure 2)

Q: Please try to explain what happened on the genes between parents (F1) and babies (F2)?

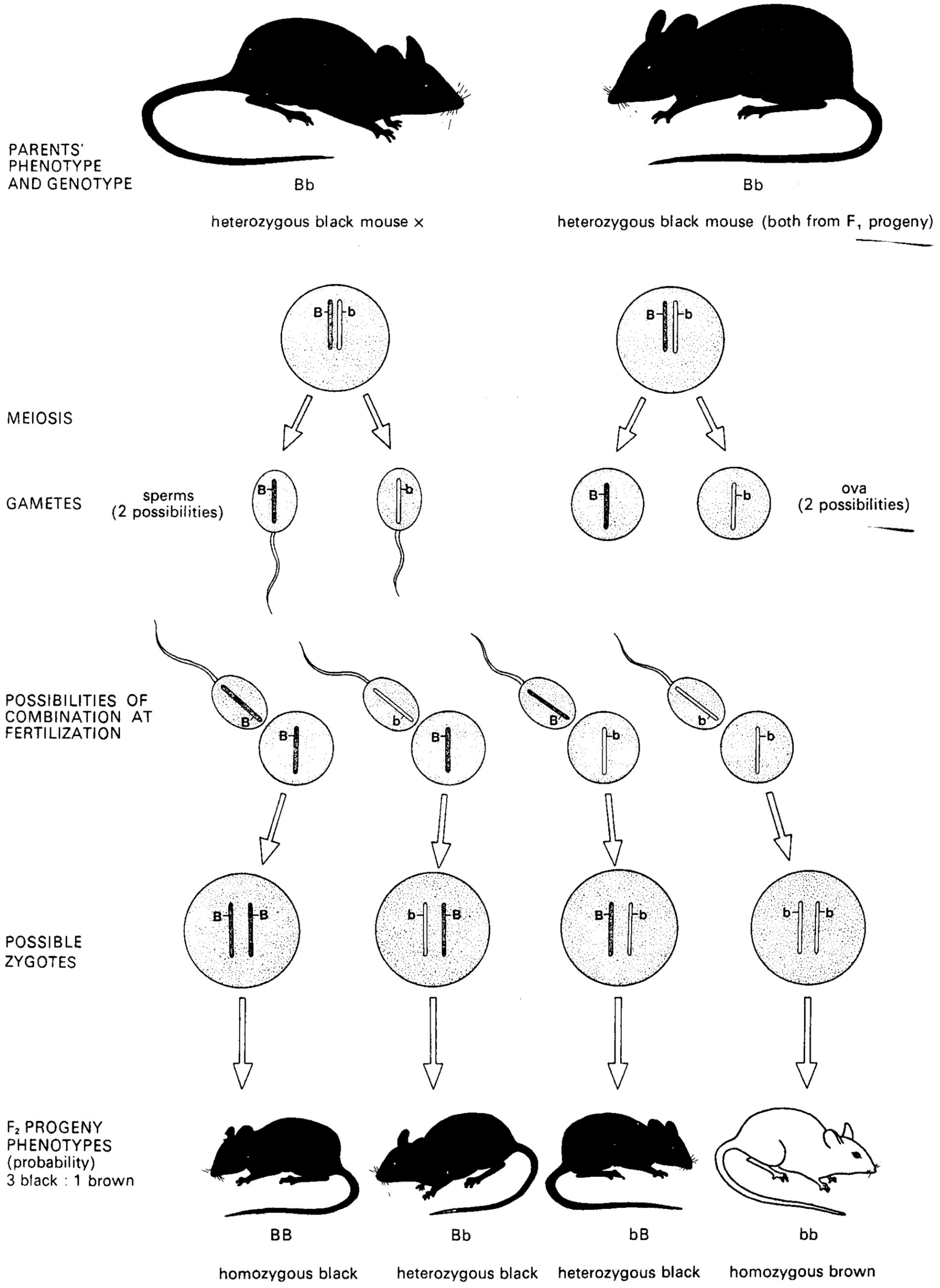

PARENTS' PHENOTYPE AND GENOTYPE
Bb
heterozygous black mouse ×
Bb
heterozygous black mouse (both from F₁ progeny)
B
b
MEIOSIS
GAMETES
sperms
(2 possibilities)
ova
(2 possibilities)
POSSIBILITIES OF COMBINATION AT FERTILIZATION
POSSIBLE ZYGOTES
F₂ PROGENY PHENOTYPES
(probability)
3 black : 1 brown
BB
homozygous black
Bb
heterozygous black
bB
heterozygous black
bb
homozygous brown

Figure 2

(5) The appearance of brown fur in the second generation is evidence of the fact that the F1 black mice carried the recessive gene for brown fur, even though it did not find express in their observable features, phenotype.

When these black F1 mice produce gametes, the process of meiosis will separate the chromosome carrying the B and b genes so that half the sperms of the male parent will carry B and half will carry b. Similarly, half the ova from the female will contain B and half b. At fertilization, there are equal chances that a B-carrying sperm will fuse with either an egg carrying the B gene or an egg with the b gene, so producing either a BB or a Bb zygote. Similarly there are equal chances of a b-carrying sperm fusing with either a B- or a b-carrying ovum to give bB or bb zygotes.

These results in the theoretical expectation of finding, in every four F2 offspring, one pure-breeding black mouse BB, one pure-breeding brown mouse bb, and two "impure" black mice Bb.

Please take a look: ***Timeline of Genetics!***

1655 - Robert Hooke of Britain designed his own microscope and discovered matter made up of what he called cells.

1759 - C.F. Wolff of Germany proposed a general cell theory.

1857 - **Gregor Mendel**, an Austrian monk, began experiments with pea plants. He later became known as the "father of genetics."

1859 - English biologist **Charles Darwin** published "On the Origin of Species," explaining units of heredity and variations in species.

1882 - German biologist Walther Fleming used dyes to stain cells; he discovered rods he called "chromosomes."

1892 - August Weismann published an essay on heredity. He proposed heredity was transmitted by a substance with a "chemical and molecular constitution"--he greatly influenced subsequent biologists.

1902 - American biologist Walter Stanborough Sutton demonstrated that chromosomes exist in pairs that are structurally similar.

1903 - Sutton proved that sperm and egg cells have one of each pair of chromosomes.

1908 - American biologist **Thomas Morgan** with Alfred H. Sturtevant of the U.S. showed that genes were located on chromosomes; he experimented with Drosophelia (fruit flies) to investigate sex chromosomes, and discovered X and Y chromosomes, sex-linked traits, and crossing-over.

1909 - Danish botanist Wilhelm Johannsen proposed that each portion of a chromosome that controls a phenotype be called a "gene" (Greek: "to give birth to").

1941 - George W. Beadle the U.S. and Edward L. Tatum of the U.S. discovered that genes control the production of enzymes.

1952 - **Francis H. C. Crick** of Britain and **James D. Watson** of the U.S. made a model of the DNA molecule and proved that genes determine heredity. Then discover chemical structure of DNA, starting a new branch of science--molecular biology.

1966 - The Genetic code was discovered; scientists are now able to predict characteristics by studying DNA. This leads to genetic engineering, genetic counseling.

1982 - The first recombinant DNA drug approved by the FDA--genetically engineered insulin for diabetics.

1988 - An international team of scientists began the project to map the human genome.

The Late 1980's - The first crime conviction based on DNA fingerprinting, in Portland Oregon.

1990 - Gene therapy was used on patients for the first time.

1994 - The FDA approved the first genetically engineered food--FlavrSavr tomatoes engineered for better flavor and shelf life.

1997 - Dolly the Sheep--the first adult animal clone.

1998 - Three generations of mice were cloned from the nuclei of an adult, eight identical calves were cloned, the rough draft of the human genome map was produced.

Theory of Heredity—Mendelism (2)

A pattern of inheritance has emerged linking the result of experimental crosses and the combination of gametes during sexual reproduction. This pattern can be following using a ***Punnett square***.

(1) The two forms of a gene controlling a characteristic are called ***alleles***. Thus, the gene controlling the colour of mice has two alleles, one for blackness and one for brownness.
We can work out the expected results when offspring are born. We use letters to represent the alleles instead of writing it out in full. A capital letter represents a dominant allele and the corresponding small letter represents the recessive allele.

The colour of mice

B = allele for blackness
b = allele for brownness

- The genotype of the pure-breeding black mice = BB.
  This shows that such mice have 2 alleles for blackness.
- The genotype of the pure-breeding brown mice = bb.
  This shows that such mice have 2 alleles for brownness.

The cross is written (the two mice breed and have an offspring):

P: Phenotype	Black	x	Brown
P: Genotype	BB	x	bb
P: Gametes	All B		All b

↓

F1: Genotype	Bb
F1: Phenotype	All Black

Punnett square to show combination of gametes:

Gametes

		B	B	
Gametes	**b**	Bb	Bb	***Offspring***
	b	Bb	Bb	

Cross the F1 generation (two of the offspring now mate and produce offspring):

F1: Phenotype	Black	x	Black
F1: Genotype	Bb	x	Bb
F1: Gametes	B or b		B or b

↓

F2: Genotype	?
F2: Phenotype	?

Punnett square to show combination of gametes:

Gametes

		B	b	
Gametes	**B**	BB	Bb	***Offspring***
	b	Bb	bb	

F2: Genotype	BB, Bb, Bb, bb
F2: Phenotype	Black : Brown = 3:1

(2) *Practice:*

Q: In the pea plants, tallness is dominant to dwarfness. Suppose pure-breeding tall plants (TT) were crossed with pure-breeding dwarf plants (tt), and then follow the cross through to the F2 generation.
Please predict all the offspring.

Cross the pure-breeding tallness and pure-breeding dwarfness:

P: Phenotype	Tall	x	Dwarf
P: Genotype	____	x	____
P: Gametes	____		____

↓

F1: Genotype	____________
F1: Phenotype	____________

Using Punnett square to show combination of gametes:

	Gametes	
	____	____
____	____	____
____	____	____

Gametes (rows) — Offspring (shaded cells)

Cross the F1 generation:

F1: Phenotype	____	x	____
F1: Genotype	____	x	____
F1: Gametes	____		____

Using Punnett square to show combination of gametes:

	Gametes	

Gametes (rows) — Offspring (shaded cells)

F2: Genotype	____________
F2: Phenotype	____________

Q: Now try to fill in this table.

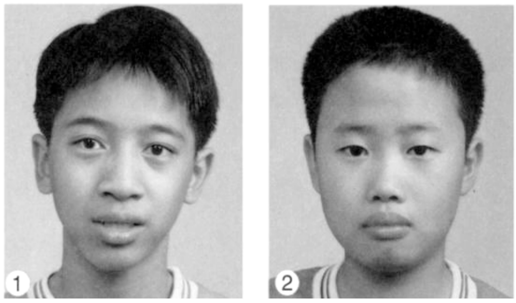
Genotype of parents	*Genotype ratio of offspring*	*Phonotype ratio of offspring*
AA x **AA**		
aa x **aa**		
AA x **aa**		
AA x **Aa**		
Aa x **aa**		
Aa x **Aa**		

Human Inheritance (1) – Gamete combination

Using Punnett squares allows us to predict the ratios in crosses. These ratios may differ from those in experimental crosses.

Part 1

The double-fold/single-edged eyelid is a trait inherited from our parents (Figure on right).
The gene for double-fold eyelid is dominant (R) to that for single-edged eyelid (r).



Double-fold eyelid/Single-edged eyelid

If the genotypes of a couple are Rr x Rr, please use the Punnett squares to predict the ratios in crosses.

The types of offspring genotype ______ ______ ______ ______
The phenotype ratio of offspring ____________________________

Part 2

Use the cards to represent chromosomes. The letter on the card represents a gene:
R is the gene of double-fold eyelid and r is the gene of single-edged eyelid.

R **r** x **R** **r**

(9) You will be working in a group of three:
One member will act as the ***father***;
One member will act as the ***mother***; and
One member will act as the ***child***.

(10) The father will hold the grey cards and the mother the white cards. The grey cards represent the chromosomes in the father's cell, and two white cards represent those in the mother's cell.

(11) One student is to play the father taking two grey cards, and the other student is to play the mother taking two white cards. Place the cards face to yourself.

(12) The third student (playing child) picks one card from the father and one from the mother without looking and then links them together. (So he/she will get one grey card and one white card). This means the gene combination of the first offspring.

(13) Record this result on the following table, and then give the cards back to the parents.

(14) Repeat 3 times.

(15) List the genotypes obtained. Beside each genotypes state the phenotype.

(16) Repeat 16 times.

Number	Genotype	phenotype	Number	Genotype	phenotype	Number	Genotype	phenotype	Number	Genotype	phenotype	Number	Genotype	phenotype
1			5			9			13			17		
2			6			10			14			18		
3			7			11			15			19		
4			8			12			16			20		

Answer the following questions.

8. Work out the ratio of phenotype from data 1 to 4.
   The double-fold eyelid's number: ___________
   The single-edged eyelid's number: ___________
   The double-fold eyelid : the single-edged eyelid = ___________

9. Work out the ratio of phenotype from data 1 to 20.
   The double-fold eyelid's number: ___________
   The single-edged eyelid's number: ___________
   The double-fold eyelid : the single-edged eyelid = ___________

10. Collect all data from all classmates and work out the ratio of phenotype.
    The double-fold eyelid's number: ___________
    The single-edged eyelid's number: ___________
    The double-fold eyelid : the single-edged eyelid = ___________

11. Arrange your data:
    Punnett square to show the ratio phenotype is ___________
    From data 1 to 4 the ratio of phenotype is ___________
    From data 1 to 20 the ratio of phenotype is ___________
    From all classmates' data ratio of phenotype is ___________

12. If we compare the ratio of dominant and recessive in four children family and twenty children family, which result is close to the theory?

13. After collecting the data from all classmates, how does the ratio of dominant and recessive compare between this experiment and theory?

14. Explain why the actual ratios may differ from the predicted ratios.

Human Inheritance (2) – Comparing with Each Other

Some people are tall and some are small. Some people have skin while some people have light skin. These characters are called ***traits***. There are *thousands* of human traits.

In this activity, let us look only at 9 human traits.

Part 1

Please check yourself by using a mirror and then write it down.
Look at the pictures on the next page to help you.

Trait	Dominant	Recessive
Bend of thumb	Straight	Hitch-hiker's (Bend)
Beauty tip of fore hair	Yes	No
Forefinger	Longer than ring finger	Shorter then ring finger
Tongue roller	Yes	No
Both hands hold together	Left thumb is on top	Right thumb is on top
Eyelid	Double-fold	Single-edged
Eyelid	Double	Single
Dimple	Yes	No
Colour blindness	Normal (29)	Colour blindness (70)

Trait	Yours
Bend of thumb	
Beauty tip of fore hair	
Forefinger	
Tongue roller	
Both hands hold together	
Eyelid	
Dimple	
Colour blindness	

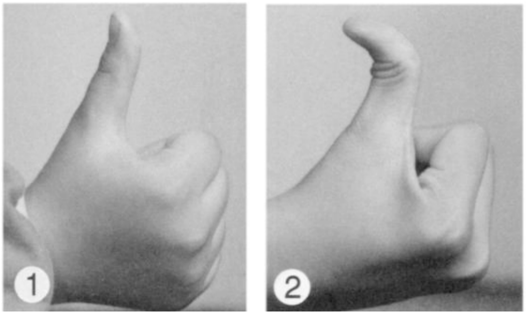


Fig 1: Bend of the thumb.
Straight/Hitch-hiker's (Bend)

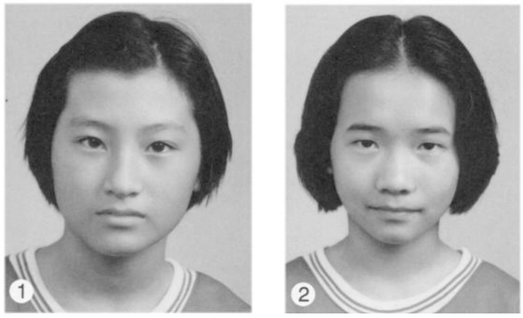


Fig 2: Beauty tip of fore hair.
Yes/No

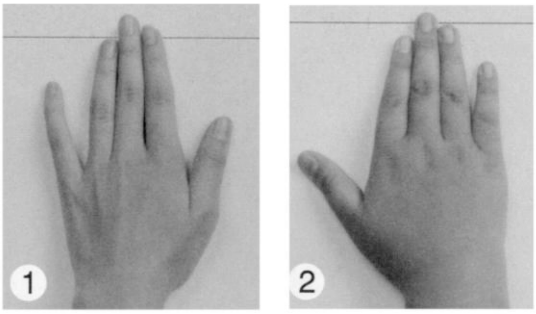


Fig 3: Forefinger.
Longer/Shorter than the ring finger

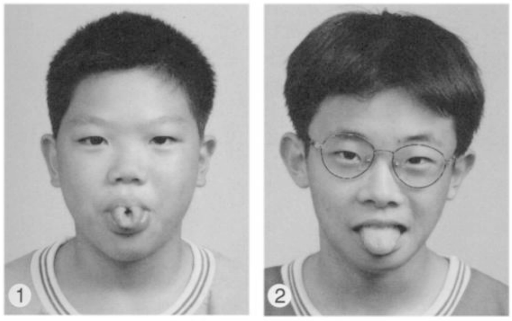


Fig 4: Tongue roller.
Yes/No

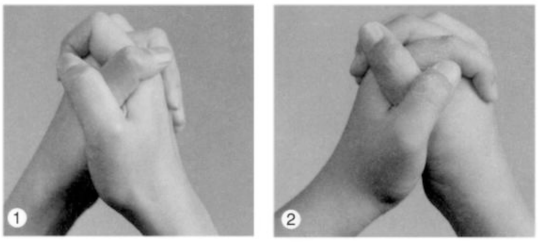


Fig 5: Both hands hold together.
Right/Left thumb is on top

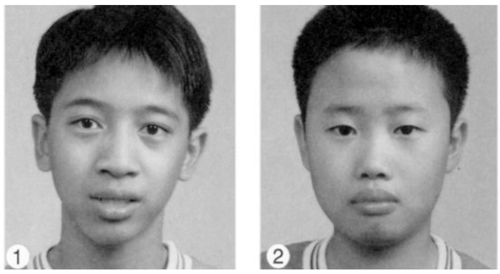


Fig 6: Eyelid.
Double-fold/Single-edged

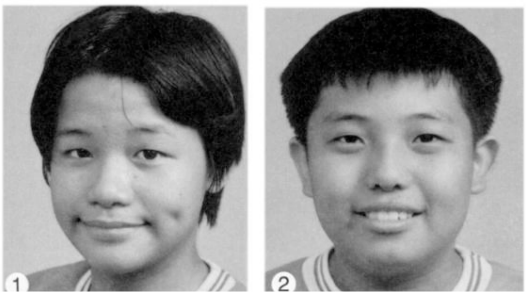


Fig 7: Dimple.
Yes/No

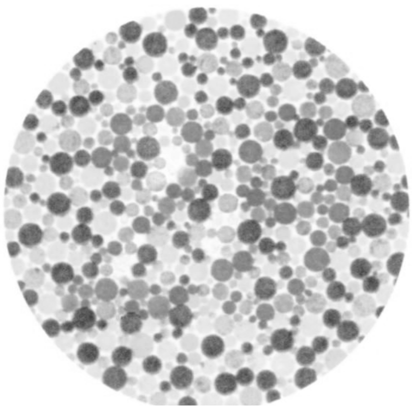


Fig 8: Colour blindness.
Normal (29)/ Colour blindness (70)

Part 2

All students in the class stand up, and check all traits one by one with teacher (or one student).

> The teacher says his/her trait starting the first one (earlobe).
> If your trait is different, sit down.
> Then check second trait (tongue roller).
> If your trait is different, sit down.
> Go through each trait in turn: if your trait is different from teacher, sit down.
> And go on…

Answer these questions:

(1) How many students are still standing at the end?

(2) If no one stands at the end, what does this mean?

(3) If some students are still standing at the end, what does this mean? Are their other traits the same as well?

(4) According to this activity, how many possibilities are two persons' (not twins) all traits the same?

Compare with your family after you go home.

- How would you predict the results compared to your classmates?
  Explain any differences.

Sex Determination

Sex is also a characteristic determined by inheritance.

In humans, one pair of chromosomes determinates gender. This pair is called ***sex chromosomes***.

As you can see at right figure, there are 23 pairs of human chromosomes arranged by length. In female, this pair of sex chromosomes is XX; in male, this is XY.

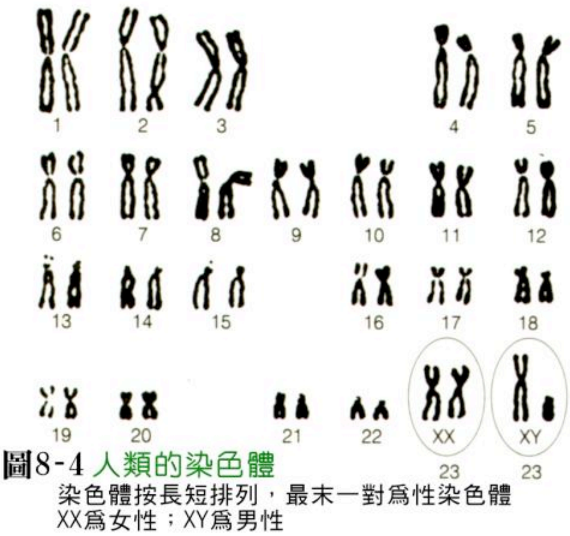


Figure: Human's chromosomes
(The last pair is sex chromosomes labelled no. 23. Female is XX and Male is XY.)

Part 1

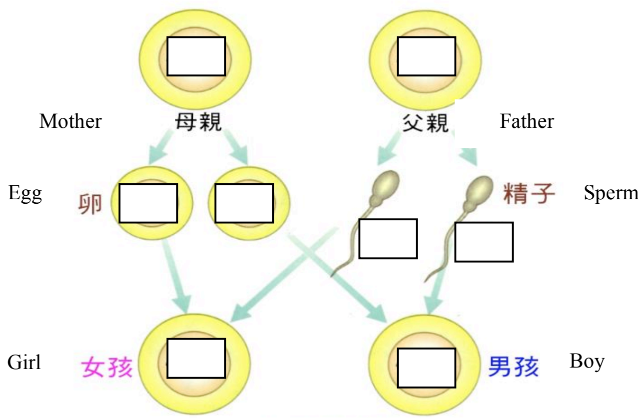
From your previous work on gamete formation and fertilization, please try to fill the blank spaces in the following picture and explain how the sex of a child is determined.

Place the letters XX, XY, X, or Y in the appropriate circles to show the passage of the X and Y chromosomes from the egg and sperm forming cells to the fertilized egg.

Remember:

(1) Each gamete has only one set of chromosomes.

(2) Each male gamete could join in with either female gamete.



Sex determination

Read this:

This pair of sex chromosomes separate from each other when cell undergo meiosis.

The results turn out to be 22+X (egg from the mother) and 22+X or 22+Y (sperms from the father).
This means 22 somatic chromosomes and one sex chromosome. （In the last practice, we do not write the 22 somatic chromosomes, and just write sex chromosomes; X and Y.）

When an egg is fertilized with 22+X sperm, it is going to be a girl.
When an egg is fertilized with 22+Y sperm, it is going to be a boy.

Part 2

Now answer these questions:

(1) How many chromosomes are in a sperm? __________
How many sex chromosomes are in a sperm? __________
What's the sex chromosome in a sperm? __________

(2) How many chromosomes are in an egg? __________
How many sex chromosomes are in an egg? __________
What's the sex chromosome in an egg? __________

(3) How many chromosomes are in a male's body cell? __________
How many sex chromosomes are in a male's body cell? __________
What's the sex chromosome in a male's body cell? __________

(4) How many chromosomes are in a female's body cell? __________
How many sex chromosomes are in a female's body cell? __________
What's the sex chromosome in a female's body cell? __________

(5) Does the father's or mother's gamete determine the sex of a child? __________

Part 3

(1) Now look at the following picture. Two red X represent a mother's sex chromosomes, and two blue (X and Y) represent a father's sex chromosomes.

Please fill the following chessboard square, and then predict the sex of their children.

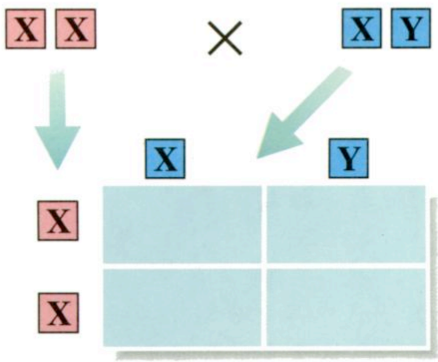


圖8-16 人類的性別的遺傳

More Questions to Answer

(2) XX : XY = __________

(3) Boys : Girls = __________

(4) The boy's Y chromosome comes from ….. __________

(5) The boy's X chromosome comes from ….. __________

(6) The girl's X chromosome comes from ….. __________

These are a little Harder

(7) What is the chance that parents have a boy? __________

(8) If the first baby is a boy, what are the chances that the parents have another boy?

____

(9) What is the chance that parents have two boys? __________

(10) If both of the parents' eyelids are double (**Aa** x **Aa**),

what are the chances that they have a boy with single eyelids? __________

Genetics in our lives

Shrek said:

I'm going to marry Princess Fiona. The king of the kingdom of far far away asks us to do genetic counselling in the hospital.

Princess Fiona said:

I saw some food in the supermarket is labelled GM Food. What's that? And if I eat that, does that make me become normal both day and night.

Prince charming said:

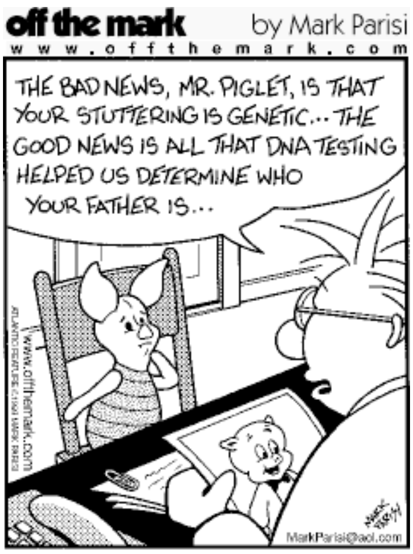
Last week's news indicated that scientists are researching on human cloning! If it is possible, I am going to clone a lot of myself, charming human being.

Donkey said:

I heard genetic engineering and biotechnology are very hot nowadays. They can help agriculture breeding, but also produce medicines. Maybe I'll become a horse one day!

Genetics is more and more important in our lives.

Please surf the following websites and answer questions.



Part 1: Genetic counselling

Find the following site: http://sp1.cto.doh.gov.tw/doctor/book/ch02/book2_2.htm

(1) What is genetic counselling?
(2) Who needs to do this?

Find the following site: http://nature.ckps.tpc.edu.tw/6b/%BF%F2%B6%C7/tree-chap8.htm

(3) What is the carrier of a genetic disease? Answer: ___________ (A) A patient with a genetic disease. (B) A healthy person who has a disease gene. (eg. genotype is Aa)

Find the following site: http://www.commonhealth.com.tw/New_Life/baby/exam2.htm

(4) Pedigree is very important when we do genetic counselling. How do doctors know you are not a carrier of genetic disease?

Find the following site: http://content.edu.tw/junior/bio/tc_wc/textbook/ch08/supply8-6-1.htm

(5) How is genetic counselling carried out?
(6) If you needed it, where could receive genetic counselling? (Choose one where is the nearest your home.)

Part 2: Genetic engineering

Find the following site: http://nature.ckps.tpc.edu.tw/6b/%BF%F2%B6%C7/tree-chap7.htm

(1) In using genetic engineering to produce insulin, what kind of organism do we use to produce insulin?

Find the following site: http://life.nthu.edu.tw/~b851622/Biology/Dolly[1].htm

(2) Dolly was a cloned sheep. Dolly had three mothers. One provided a nucleus from a breast cell, the other donated an egg. The third mother was pregnant with Dolly. Which mom did Dolly originate from? Why?

Find the following sites: http://www.bud.org.tw/answer/9904/990445.htm
http://www.bud.org.tw/answer/0108/010830.htm

(3) What are your views about cloning human beings?

Find the following sites: http://food.doh.gov.tw/gmo/qa.htm

(4) See the DM from our ministry of health. Do you think GM food is safe? Why?

Cloning Humans

Right or Wrong?

Please read the papers that your teacher gives you and discuss the following questions.

You will be working in a small group of about three.
Do not try to work on your own!!

After you have discussed each question,
you can take it in turns to record your agreed answers.

One of you may be asked to report back on your answers to question 6.

(1) As a group, list as many benefits you can think of which could come from human cloning.

(2) What are the drawbacks which might occur with human cloning?

(3) Do you think cloning can cause ethical (things about right and wrong) problems?

(4) There are three types of parents: gene parents, delivery parents, and care parents? What kinds of legal problems might arise?

(5) What do you think different religions might have to say about human cloning? Will it change our beliefs?

(6) As a group, do you think human cloning is a good idea? Give your reasons.

Homework

Please write a letter to the British Queen (no more than 6 sentences).

1. Tell her your opinions about human cloning.
2. Give her some reasons why you recommend or reject that human cloning should be allowed in the UK.

Appendix E

Word association test

Think of a Word

When you hear or see a word, it often makes you think of other words.

In this study we should like to find out what other words are brought to your mind by some words used in Genetics.

On each page you will find a key word written many times. Say the word to yourself, and then, as quickly as possible, write the first word that comes to your mind in the spaces provided. Fill up as many spaces as you can.

Continue in this way until you are told to turn to the next page.

There are no right or wrong answers.

Write as quickly as possible since you are only allowed 30 seconds for each page.

Thank you very much!

Centre for Science Education, University of Glasgow, U.K.

Your Basic Information

Name: __________ Sex: □ Boy □ Girl

Class: __________ Number: __________

Here is an example:

For the word: **FALCON**

Here are some possible words which come to mind

FALCON	1......BIRD
FALCON	2......FLY
FALCON	3......NEST
FALCON	4......CLAW
FALCON	5.......FEATHERS
FALCON	6.......BEAK
FALCON	7.......BALD
FALCON	8.......PREY
FALCON	9.......PRESIDENT
FALCON	10.....TREE

Here is another example:

PHOTOSYNTHESIS

PHOTOSYNTHESIS	1....PLANTS
PHOTOSYNTHESIS	2....CHLOROPHYL
PHOTOSYNTHESIS	3....CARBON FIXATION
PHOTOSYNTHESIS	4....SUN LIGHT
PHOTOSYNTHESIS	5.....O_2 PRODUCTION
PHOTOSYNTHESIS	6....CHEMICAL ENERGY
PHOTOSYNTHESIS	7....STARCH
PHOTOSYNTHESIS	8....TEMPERATURE
PHOTOSYNTHESIS	9....AMAZON FORESTS
PHOTOSYNTHESIS	10....LIFE

Your task is to write as many words as possible
that come to your mind in the time available.

Do not turn over until told to do so!

GENE

GENE	1..
GENE	2..
GENE	3..
GENE	4..
GENE	5..
GENE	6..
GENE	7..
GENE	8..
GENE	9..
GENE	10..

TRAIT

TRAIT	1..
TRAIT	2..
TRAIT	3..
TRAIT	4..
TRAIT	5..
TRAIT	6..
TRAIT	7..
TRAIT	8..
TRAIT	9..
TRAIT	10..

DOMINANT

DOMINANT	1..
DOMINANT	2..
DOMINANT	3..
DOMINANT	4..
DOMINANT	5..
DOMINANT	6..
DOMINANT	7..
DOMINANT	8..
DOMINANT	9..
DOMINANT	10..

HEREDITY

HEREDITY	1...
HEREDITY	2...
HEREDITY	3...
HEREDITY	4...
HEREDITY	5...
HEREDITY	6...
HEREDITY	7...
HEREDITY	8...
HEREDITY	9...
HEREDITY	10..

CHROMOSOME

CHROMOSOME 1..

CHROMOSOME 2..

CHROMOSOME 3..

CHROMOSOME 4..

CHROMOSOME 5..

CHROMOSOME 6..

CHROMOSOME 7..

CHROMOSOME 8..

CHROMOSOME 9..

CHROMOSOME 10..

BIOTECNOLOGY

BIOTECNOLOGY 1..

BIOTECNOLOGY 2..

BIOTECNOLOGY 3..

BIOTECNOLOGY 4..

BIOTECNOLOGY 5..

BIOTECNOLOGY 6..

BIOTECNOLOGY 7..

BIOTECNOLOGY 8..

BIOTECNOLOGY 9..

BIOTECNOLOGY 10..

CLONING

GM FOOD

GM FOOD	1...
GM FOOD	2...
GM FOOD	3...
GM FOOD	4...
GM FOOD	5...
GM FOOD	6...
GM FOOD	7...
GM FOOD	8...
GM FOOD	9...
GM FOOD	10...

MENDEL

MENDEL	1...
MENDEL	2...
MENDEL	3...
MENDEL	4...
MENDEL	5...
MENDEL	6...
MENDEL	7...
MENDEL	8...
MENDEL	9...
MENDEL	10...

HUMAN GENOME PROJECT

HUMAN GENOME PROJECT 1...

HUMAN GENOME PROJECT 2...

HUMAN GENOME PROJECT 3...

HUMAN GENOME PROJECT 4...

HUMAN GENOME PROJECT 5...

HUMAN GENOME PROJECT 6...

HUMAN GENOME PROJECT 7...

HUMAN GENOME PROJECT 8...

HUMAN GENOME PROJECT 9...

HUMAN GENOME PROJECT 10...

End

Thank you very much!

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