University
of
Glasgow

The Development of Scientific Thinking with Senior School Physics Students

By

Fatheya Mahmood Abdulla Al-Ahmadi

BSc (Physics and Education)

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy (PhD)

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

© Fatheya Mahmood Abdulla Al-Ahmadi, April 2008

Dedication

I would like to thank and bow to the two people who were the real cause of my success today, the two who helped me to reach to this stage in the path of my life and to meet the goal of my ambition that I had always dreamt about it since the beginning of my childhood. Unfortunately they are not here with me to celebrate their success, not just mine. Anyhow I have a feeling that they are spiritually here with me while actually they had to leave me a long time back for the kingdom of heaven with God. I salute my Mother and Father.

Water quenches the thirst, Knowledge quenches the ignorant.

"Seek for knowledge wherever it is" (Prophet Muhammed)

ماذا كان يقول قايدنا الاسطورة موسس دولة الامارات العربية المتحدة و باني حضارتها الماذا كان
يقول قايدنا الاسطورة موسس دولة الامارات العربية المتحدة و باني حضارتها الحديثة عن المراة و
العلم الشيخ زايد بن سلطان ال نهيان رحمه الله

What our late great president, Sheik Zayed Bin Sultan, the founder of United Arab Emirates had to say about knowledge and women:

ان المراة نصف المجتمع ، وهي ربة البيت ولا ينبغي لدولة تبنى نفسها ان تبقي على
نصف مجتمعها غارقة في ظلام الجهل ، اسيرة لاغلال القهر ، مقيدة مشلوله الحركه .

Women are half of the society and she is the one that brings up the family. No country can survive if it leaves half of its population illiterate, living in darkness, helpless, conquered and handcuffed by a chain of ignorance.

العلم كالنور يضى المستقبل وحياة الانسان لانه ليس له نهاية ولابد ان نحرص عليه فالجاعلم
كالنور يضى المستقبل وحياة الانسان لانه ليس له نهاية ولابد ان نحرص عليه فالجاهل هو الذي
يعتقد انه تعلم واكتمل في علمه اما العاقل فهو الذي لا يشبع من العلم اذا اننا نمضي حياتنا
كلها نتعلم

Knowledge is like a light shining into the future for human life because light has no limit and we must take knowledge seriously and adopt it well. The ignorant person is the one who thinks he knows everything and has learned everything and the wise is the one who seeks the source of knowledge and always search for more. Living means learning throughout Life.

Abstract

The phrases like ‘scientific thinking’, ‘scientific method’ and ‘scientific attitude’ are all widely used and frequently appear in school curriculum guides but the meaning of such phrases is much less clear. In addition, there is little about how such skills might be taught or assessed. In the light of this, this thesis is a study which focusses on several related areas: the meaning of scientific thinking will be explored and the features of scientific thinking which make it uniquely different from other kinds of thinking will be analysed, set in the context of what is known about how conceptual learning takes place; the measurement of scientific thinking skills will be attempted and ways by which scientific thinking can be taught in the context of physics will be developed.

There are two possible hypotheses which arise in this study: genuine scientific thinking is not accessible until learners have matured developmentally and have sufficient experience of the sciences. The way the sciences are taught will encourage or hinder the development of such skills. The empirical work was conducted in three stages to explore these hypotheses. Overall, 1838 students were involved in the study.

The first experimental study was carried out with students (boys and girls) aged 15-18 from various schools in the Emirates and seeks to explore the extent to which they are thinking scientifically as well as making several other measurements of their abilities and attitudes. A test for measuring scientific thinking, based on physics, was developed and used along with an established test of working memory capacity, known to be a rate determining factor in much learning. In addition, a test to measure understanding of ideas in physics was constructed and used and the national examination marks for these students in the three sciences and mathematics were considered. It was found that the test of scientific thinking, the test of understanding physics and the national examination marks measured very different outcomes which are likely to be: scientific thinking, understanding and recall, respectively.

In the second stage, some of the measurements completed in the first stage were repeated to confirm the outcomes. However, the main part was the development and use of five teaching units which, together, aimed to teach the key skills which had been defined as scientific thinking. The success of this was measured by using the same test of scientific thinking and comparing the outcomes to those obtained in the previous experiment. In addition, the results from the use of two of the items in the test of scientific thinking were compared to the outcomes compared in a previous study (using the same items) which had been based on large samples of younger students (aged 12-15). A survey was also used to see how the students saw themselves in relation to their study in physics.

It was found that the use of the units had improved scientific thinking significantly with the younger two groups (age 15-16 and 16-17) but no improvement was observed with the oldest group (age 17-18). It was also found that the older groups of students were significantly better in the skills measured by the items used by the previous study when compared with younger students. The outcomes of the survey showed that their self-perceptions related poorly to their abilities in thinking scientifically while the interests of boys and girls were remarkably similar, suggesting that physics could appeal equally to both genders. In addition, there is clear evidence that all students want their studies in physics to relate to the real issues of life which are important for them and that boys are less willing to memorise than girls.

The third phase employed the academic game known as Eloosis (which is considered to be an excellent model of scientific thinking) with three groups: one group had completed studies in one or more of the sciences and were about to leave school; one group were studying for a degree in an arts subject and were unlikely to have had much experience in the sciences; the third group had all graduated in a science discipline recently. While all groups played the game excellently, the group who had little or no science background did not appreciate the significance of the game as it illustrated the way science works in exploring the world around while both the senior school students and the science graduates, without prompting, could express a clear conception of the way science works although the graduate group, understandably, used more sophisticated language.

The overall conclusions are that the test of scientific thinking certainly measures something completely different from the other measurements and, linked to the outcomes of the academic game, it does appear that it measured something close to scientific thinking. If this is true, then such thinking can be taught but is not accessible to those younger than aged about 15-16. All of this is consistent with the type of observations made by Piaget many decades ago and suggests that any attempts to develop scientific thinking with young adolescents will be unlikely to be successful. However, with older adolescents, for the skills to develop, there needs to be some teaching of this way of thinking. With the very large sample sizes and good cross-section of the population, there is reasonable confidence that the conclusions are generalisable and can inform future practice.

Acknowledgements

First I should like to thank the people of Glasgow city for their hospitality and their sense of humour. I am grateful to my country and all that it has given me in my education as well as being grateful to all friends in Abu Dhabi for providing the spiritual encouragement during the years of my study and I express my appreciation to the United Arab Emirates Embassy staff in London for their practical support.

My special thanks to Professor Norman Reid who has guided me at every stage and my appreciation to Professor Rex Whitehead for his advice and encouragement.

My sincere grateful thanks goes to all my dear brothers for their support and encouragement, specially to my brother Ali who offered me his holiday flat in Scotland during the entire period of my study. I have enjoyed the friendship and support from so many in the Centre for Science Education, for the fun and the laughter and all that we shared together. Special thanks are due to Mrs. Norma de Vilbiss for her assistance with English and for sharing her home with me so willingly.

My sincere thanks must go to Abu Dhabi Education zone as well as the Ministry of Education for their assistance and help. I am grateful to schools and students in Abu Dhabi schools for all their help and, especially, my thanks to Mrs. Sedika Al Qasmi.

Fatheya Al Ahmadi

Table of Contents

List of Tables

List of Figures

Chapter One

Introducing the Study

1.1 Aims of Education

Education plays a major role in any society today. It is important to pass on to the next generation something of the accumulation of knowledge and experience of past generations. However, it is important that learners can apply the knowledge they have gained. In the United Arab Emirates, as with many countries, there are major issues in developing a well trained manpower. This can be seen not so much in what they have memorised but in what they can contribute to the society. This explains the recent very high emphasis on education in the country.

It is also important that the education system develops young minds that are capable of thinking, weighing evidence, analysing, and appreciating the place and value of knowledge, understanding and life-long learning. This might be considered as aspects of critical thought. In physics, as with the other sciences, there is also the issue of what is often called scientific thinking. The question arises: is this unique to the sciences or is just a part of general higher order thinking skills?

Before these issues are addressed, there is a need to offer a brief overview of the Emirates education system where the empirical work of this study is placed.

Figure 1.1 The National Flag

1.2 A Twentieth Century Vision

Sheikh Zayed observed that, '*There were a lot of dreams I was dreaming about our land catching up with the modern world but I was not able to do anything because I did not have the wherewithal in my hands to achieve these dreams. I was sure, however, that one day they would become true*.' (National Media Council, 2007). Oil production was to provide Sheikh Zayed with the means to fund his dreams, there being a massive programme of construction of schools. He believed that all of the country's citizens (men and women) had a role to play in its development. The educational opportunities in the United Arab Emirates have blossomed since the establishment of the federation in 1971.

Figure 1.2 Queen and Sheikh Zayed

1.3 The United Arab Emirates

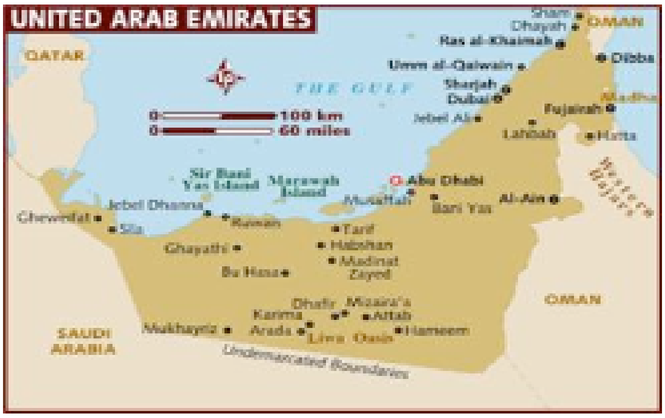


Figure 1.3 Location of the Emirates

The United Arab Emirates is a country lying towards the north east of Arabian Peninsula, between Saudi Arabi and Oman. It was formed by the union of seven emirates: Abu Dhabi, Dubai, Sharjah, Agman, Ra's Al Khayma, Umm Al Qaiwain and Al-Fujayrah. The official language is Arabic.

1.4 The Historical Development of Education

Al Taboor (2007) traces the educational history of the Emirates over the years.

Figure 1.4 Changes in Education

The education of the religious schools or Al Motaweh: This ancient system depended on the memorisation of the Qur'an and the Hadith, with training in writing and developing an the awareness of the Pillars of Islam and the religious traditions.

The education by circle group: This involved groups of learners working with more knowledgeable guides and covered themes from jurisprudence, interpretation, grammar, history and religious lessons. The groups often met in homes, the mosque or commercial premises. From these group emerged the first generation of United Arab Emirates pioneers.

An evolutionary education or semi regular education: In the years between 1907 to 1953, more formal school-based education began to emerge, the whole process evolving slowly over time. In 1936, an education department was formed in Dubai while schools began to appear in many of the towns and cities. The school declined as commercial wealth from pearl industry collapsed with the advent of synthetic pearls in the 1940s. On the rubble of these schools and through their educational experiences the first regular school was founded in the United Arab Emirates.

The regular new education: The opening of the school Al Qasmia in 1953 was the start of what became known as regular education. National curricula were developed and end of year certificates were introduced. Originally founded by local government, the system went thorough major renewal from 1971, with the emergence of the United Arab Emirates. This led to a Federal Ministry and a Ministry of Education and Youth.

The state schools were well designed and aimed to bring the whole education provision up to the highest standards with good resources and modern approaches. This led quickly to massive improvement in literacy - indeed, the eradication of illiteracy.

1.5 Recent Developments

By 2005, The United Arab Emirates made it quite clear that it saw investment in human capital as the best kind of investment in order to ensure long-term economic and social well being and that high quality education is a tool for the development of the society (Ministry of Education, 2005). The National Consultative Council (2006) offered a free, comprehensive education to all male and female students from kindergarten to university. Education in the Emirates is universal and compulsory up to ninth grade (age 16) although there is a thriving private sector in provisions at all levels. The clearly expressed aim is to ensure the youth of the country are ready to meet the challenges of the twenty-first century workplace.

1.6 Education Vision 2020

A new initiative, known as Vision 2020, seeks to offer a better educational future where all have access to a general education of the highest quality. Vision 2020 aims at making fundamental changes to educational objectives, structures, and processes in order to effect a qualitative change in educational outputs. The key points of this initiative are:

(1) Education must be well planned, with key agreed policy pillars leading to challenging but achievable strategic objectives.

(2) Education must position itself as a high level profession, based on the best understanding of theory, research and an understanding of the world's best practice.

(3) The staff working in education should have a high professional orientation with a strong belief in the values and ethics of their profession.

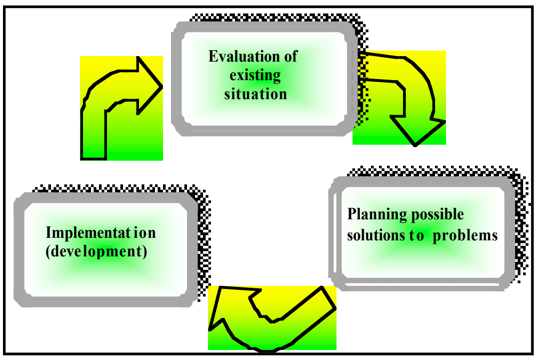
(4) Society must provide both material and social incentives to all individuals who work in the field of education. These incentives are needed to encourage highly qualified and able personnel to take up teaching as a career.

(5) The concept of the school curriculum must be fundamentally changed from a teacher-centred 'choice' and presentation of the content approach to a student-centred planning and organisation of learning opportunities approach.

(6) The participation of society in education needs to be refined. Not only is education for all but also all must be for education.

(7) Education institutions must be well-financed.

It is difficult to argue against such a national vision. It is more difficult to develop and implement the necessary changes to enable it to take place. The vision was seen as a comprehensive and cohesive plan for the development of education in the Emirates to meet the national development requirements of the 21st Century. To achieve implementation, the follow cycle of events was envisaged:



Some projects have been undertaken: in 2000, an information technology project was launched with the aim of providing one computer for every ten children in kindergarten. every five pupils in primary schools, every two students in preparatory schools and one computer per student in universities. In 2005, the Abu Dhabi Education Council was established to formulate an education plan within the framework of the United Arab Emirates general education policy, seeking for radical ways to improve the education provision. There are also ambitious developments in focussing on the development of English language and technical skills, with the science subjects and mathematics playing a large role. A national curriculum development centre has been established while many model schools have been set up, these being resourced to the highest levels. Libraries have been upgraded and a new system of secondary education is under development.

1.7 Education System

The education system at school level is organised in the following way.

Table 1.1 Structure of Education System

Education System		
Level	Age	Period of time
Kindergarten	4-5	2 years
Primary schools	6-11	5 "
Preparatory stage	12-15	4 "
Secondary schools	15-18	3 "
Technical Secondary School	12-18	6 "

The National Consultative Council (2006) is aiming that 90% of all teachers are Emirates citizens by 2020. At the moment, over 40 per cent of pupils attend private schools but some of these are for expatriate communities. One major problem in the Emirates is the way the education system has depended on those from overseas, especially from the West. The curriculum is under continual change as advisers from different countries have exerted influence by means of introducing curriculum approaches, textbooks and assessment procedures. There needs to be more stability and more emphasis on the Emirates controlling its own educational destiny.

Although the sciences have been developed almost exclusively in the West, teachers in the Emirates do not see any conflict between the sciences and Arabic culture (Haiader, 2002). Major changes may be needed in the Colleges of Education. The pace of change is so fast that it is too easy for one generation to remain in its own thought form, leaving the next generation to move on rapidly. Probably, the main area which is needed is to move the curriculum and assessment emphasis away from the emphasis on the correct memorisation of information towards much broader curriculum objectives. In the sciences, this will include an appreciation of the social impact of the sciences, the development of critical thought, and, perhaps seeing the sciences as ways of thinking rather than bodies of accumulated knowledge to be learned and recalled accurately. The whole area of school management and administration needs considerable overhaul while the problems of waste, inefficiency and low productivity are deep-seated. Accordingly, the future development of education for the next 20 years requires a new Vision.

1.8 Physics in the Emirates

Physics is taught as part of science from age 12 to age 14 (grades 7-9) although there is some simple science at earlier stages. For one year (grade 10), all students take a formal courses in physics and, after that, students may choose to take physics until they leave school (grades 11 and 12).

The physics curriculum has been changed repeatedly. For example, the physics curriculum has been changed three times since 1996 and further changes are planned. The teaching is based on a lecture approach, with some laboratory work. Although the curriculum suggest that the aims centre around understanding and seeing the way physics relates to life (including careers), the assessment system places very strong emphasis on recall of information and procedures. Therefore, teachers and students work towards accurate memorisation in that this leads to good grades. Thus, physics is seen as knowledge to be memorised, but not as ideas to be understood or concepts to be applied. There is little emphasis on producing the educated citizen or seeing the use of physics in society.

In this, the Emirates is not unlike many other countries. It also illustrates the difficulty in translating the 2020 vision into classroom practice but there are currently numerous projects seeking to bring improvements. Perhaps, the key lies in the assessment. When assessment gives credit for wider skills, then the emphasis in the teaching and learning will change. In general, physics is not very popular at the later stages of school.

1.9 Scientific Thinking

Most students who undertake courses in physics will not become physicists or even scientists. However, whatever they follow as a career, they will be citizens. Their knowledge of physics may be soon forgotten, but, perhaps their attitudes to physics and the implications of physics for society may be remembered. In addition, a course in physics should offer to the learner insights into how a science subject operates in gaining its understandings of the world around. As a science, physics uses scientific thinking as its strategy for enquiry. However, although phrases like 'scientific thinking', 'scientific method' and 'scientific attitude' are all widely used and frequently appear in curriculum guides, the meaning of such phrases is much less clear. In addition, there is little about how such skills might be taught or assessed.

This is the focus of this thesis where the meaning of scientific thinking will be explored, its measurement will be attempted and possible ways by which it can be taught in the context of physics will be developed.

1.10 This Study

The teaching of physics in the Emirates is very much based on a lecture style, with the students being encouraged to memorise information and procedures and apply these correctly in examinations. There is more or less no emphasis on thinking skills, on open-ended problem solving or, specifically, on scientific thinking. This study seeks to explore such scientific thinking skills.

It is possible that these skills are not accessible for students at school level, perhaps because of their stage of cognitive development or perhaps because their experiences in physics are not sufficiently broad. It is equally possible that these skills are not being seen very much simply because they are rarely taught.

The next two chapters consider the findings from developmental psychology to see what is known about the way thinking skills like scientific thinking become accessible to learners. The possibility of cognitive acceleration is then discussed. Of course, physics is well known as a subject of difficulty for learners. Chapter 5 outlines the most recent findings from information processing which shows how learning takes place while the following chapter looks at the kinds of difficulties which have been observed. In the light of the conclusions drawn from developmental psychology and learning in physics, chapter eight offers a detailed analysis of what is meant by scientific thinking.

The first experimental study was carried out with students aged 15-18 in the Emirates and seeks to explore the extent to which they are thinking scientifically as well as making several other measurements of their abilities and attitudes. Against this set of findings, chapter 10 outlines how teaching materials were developed and used with the specific aim of enhancing the abilities of the students in thinking scientifically. Further measurements were also made. Finally, the academic game Eloosis was used to explore the extent of scientific thinking with three very different groups of learners.

The final chapter summarises the findings of the entire study, links these back to previous work and suggest areas where further enquiry is needed.

Chapter Two

Cognitive Development
The Contribution of Piaget

2.1 Introduction

For much of the history of mankind, children of school age were very often treated like adults with respect to learning. They were seen to be rather like empty containers into which knowledge was to be poured. The idea that thinking develops and changes through childhood and into adulthood was not considered. Piaget, trained as a biologist, started to observe children carefully as they faced various tasks and realised that learning develops with age. This led to the rapid growth of cognitive development as an area of serious study. This chapter seeks to offer an overview of the contribution of Piaget to the the idea of cognitive development.

2. 2 An Overview of Piaget

Jean Piaget's college and university interests originally were in biology but, early in his career, he became interested in children's intellectual development and he spent the last sixty years of his life gathering an impressive amount of research information pertaining to mental development (Wadsworth, 1984). In spite of his life-long work with children and his widely acknowledged contributions to psychology, Piaget's orientation is philosophical rather than psychological. Hyde (1970) has described the work of Piaget as that of trying, by the direct method of question and answer, to discover in what ways a child's reasoning differs from that of an adult.

Wadsworth (1984) noted that Piaget's work was not directly concerned with predicting behaviours nor was he directly concerned with how to teach children. His work was primarily concerned with describing and explaining in a very systematic way the growth and development of intellectual structures and knowledge.

Piaget set out to do something which few had attempted before. He went and looked at children and he gave them problems, some of which were practical and others verbal. He recorded both their behaviour and their verbal comments, always looking to infer the kind of reasoning which these implied (Lunzer, 1976). One of his major contributions was to find that children did not operate cognitively in the same way as adults (Hyde, 1970). His impact on education has been considerable although Egan (1983) noted that Piaget is certainly 'more read about than read'.

The relationship between the psychological and epistemological is not easy (Piaget, 1977). Piaget's view is that the shared nature of the phenomena leads to their common subordination to the laws of evolution. But this answer is still inadequate. The question must be left open until the present exposition reaches the point where it can be given a more definite form (Egan, 1983). In Piaget's view, '*teaching or training of this kind produces either very little change in logical thinking or a striking momentary change with no real comprehension*' (Egan, 1983, page 76).

2. 3 Piaget's Model of Development

Egan (1983) observed that one of the most important claims made in Piaget's model, and of special significance for educators, is that learning is constrained by development. Piaget concludes that 'teaching children concepts that they have not attained in their spontaneous development is completely hopeless.' (Egan, 1983, page 63). If Piaget is right about the nature of cognitive structures, which spontaneously develop, and their relationship to learning, then we might expect to find that learning cannot significantly affect the development of structures and that children cannot be induced to learn and understand any concept before the relevant underlying structure has developed.

Hyde (1970) notes that Piaget's approach to child development is interdisciplinary. His biological background has supplied many of the concepts he uses: he thinks of a child as an organism developing in an environment. In the course of development, it adapts itself to the environment, assimilating what is needed for its growth and changing its own behaviour (accommodating) in the process. Piaget calls the part of the thought process that is responsible for the adaptation a *schema*.

However, from birth to maturity, the schemes will develop and undergo changes. As the child develops, simple schemes based on sensori-motor experience become internalised and organised into thought structures. Piaget and Inhelder (1969) refer to pre-operatory and operatory levels of thought. The former covers the period of sensori-motor development: it is a particle level culminating in what Piaget and Inhelder call a '*kind of logic of action*'.

The term 'operation' is confined to internalised actions which are grouped into coherent reversible systems of thought functioning at two main levels: the 'concrete' level preceding an understanding of conservation and the level of 'formal' thinking. The growth that takes place is known as cognitive development which is a long and complicated process, described in brief outline in the section on stages of development and illustrated.

Hyde (1970) indicates that Piaget believes that in mental life there are also regulatory mechanisms which balance what the organism gains from its environment and what it derives from maturational factors: equilibration plays an important part in Piaget's overall theory.

Although it is the genetic factors of development which interest him most, he also believes in a fundamental interaction between internal and external which is taking place throughout life but which is especially significant in childhood. In growth, there are three main influences: maturation, the physical environment and the social environment. To these Piaget adds a fourth, equilibrium: the mental mechanism which controls the other three. Piaget uses his investigations of the formation of basic concept in children to illustrate his overall model of cognitive development. Hyde (1970) notes that, for Piaget, perception, like concept formation, is a developmental process, but not the same process.

Ausubel *et al,*. (1980) observed that the essential component of Piaget's stage notion is not age but the fixed order of succession. Likewise, Wadsworth (1984) also adds that Piaget's general hypothesis is simply that cognitive development is a coherent process of successive qualitative changes of cognitive structures (*schemata*). From a Piagetian perspective, the development can be divided into four broad stages. Piaget (1964, 1965a) postulates four main factors to explain the development from one stage to another and these are summarised in table 2.1.

Stages of Intellectual Development	**Description**
Sensorimotor *(birth to 2 years)*	Differentiates self from objects Recognises self as agent of action and begins to act intentionally Achieves object permanence, realising that things exist even when no longer present to the senses.
Pre-operational *(2 to 7 years)*	Learns to represent objects by images and words Language facility and grammar expand enormously Classifies objects by a single feature eg colour or height
Concrete operational *(8-11 years)*	Can think logically about objects and events Achieves conservation of number (age 6), mass (age 7) and weight (age Can classify objects according to several features and can order them in a series along a single dimension
Formal Operational *(12 years onwards)*	Can think logically about abstract propositions Can test hypotheses systematically Becomes concerned with the hypothetical, the future, and ideological

Table 2.1 Piaget's Four Stages

Assuming that Piaget's stages and ages are approximately correct, then upper years in the primary school see the child in the concrete operational stage. Here, logical thought is developing and conservation has largely been achieved. Both of these are important in the context of any understanding of the ideas of the sciences.

In Piaget's terms, the child at this stage is capable of 'concrete operation': he is able to solve an immediate problem but fails to generalise the results (Hyde, 1970). He can, for example, allow for the height and width of jars when comparing quantities, because he can visualise a system of compensation, but, if one of the quantities is subdivided, his system breaks down, because it is not based on conservation. Furthermore, the very contradiction in this indicate that there is a conflict between perception and reasoning and thus a sign that perception is beginning to lose its hold. The process is completed in the final stage when the child achieves understanding of conservation because his reasoning, freed from the bonds of perception, is capable of logic and mathematical operations.

Piaget sees cognitive conflict in the development of understanding. He attempts to find a unifying principle in the evolution of intellectual behaviours in a wide variety of situations, especially at what he takes to be the critical ages of five to eight and eleven to sixteen years; and his enquiries into the role of intellectual development on the character of perceptual behaviour, of imagery, of memory and of language.

Moreover, Lunzer (1976) indicates that Piaget's organising scheme is something like a self-modifying programme and his logical structures can be thought of as specifying the kinds of transformations on input that occur at any stage of development. Costanzo *et al.,* (1973) remark that Piaget seems to imply that children in the 'pre operational' stage do not use intention as a basis of judgement. On the other hand, Wadsworth (1984, page 195) notes that Piaget's model suggested that teaching methods and materials should be consistent with children's levels of conceptual development. Piaget came to believe that the mind and body do not operate independently of one another and that mental activity is subject to the same laws, in general, as biological activity. This led him to conceptualise intellectual development in much the same way as biological development. He saw cognitive acts as acts of organisation of and adaptation to the environment.

Thus, Piaget (1961, p.227) suggested four broad factors that are related to all cognitive development (Table 2.2).

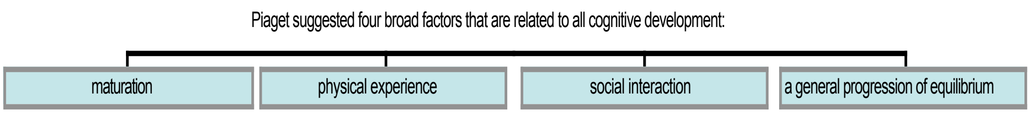


Table 2.2 Piaget's Four Factors

He viewed each of these factors and their interaction as necessary conditions to ensure cognitive development (see Wadsworth, 1984). He also believed that heredity plays a role in cognitive development, though heredity alone cannot account for intellectual development.

Piaget also asserted that cognitive development and affective development are inseparable. Thus, when cognitive development and affective development are conceptualised independently, it is no surprise that there are clear parallels between the two. This means that affective development is not independent of cognitive development although it has been presented separately. As cognitive development reaches an upper limit with full attainment of formal operations, so too does affective development. Piaget suggested that the normal and necessary intellectual and affective developments during adolescence are useful in understanding many aspects of adolescent behaviour heretofore often attributed to puberty and sexual awakening. Piaget's theory clearly has suggested that the path of cognitive development is the same for all people.

One of the great strengths of Piaget's approach is the way he brought the cognitive and affective together. He saw child development in holistic terms. Many factors affected the development but essentially, development related approximately to age and followed the same general pathway for all. The importance of the affective has often been neglected (Johnstone and Reid, 1981) and cognitive development has tended to be considered on its own. However, there is always a danger that his model is treated with too great a rigidity and wrong conclusions can sometimes be drawn. An example of this unfortunate rigidity of thinking can be seen in Shayer *et al*., (1978) where the ages-stages routine was applied with unfortunate outcomes, suggesting a model of curriculum analysis which led to wrong conclusions. Their analysis suggested certain topics were beyond the student's cognitive developmental stage but other evidence showed that students could handle them.

Wallace (1976) observes that Piaget's stage theory is couched in structures rather than process terms. Cellerier (1972) indicates two main reasons for this relative emphasis on structure rather than process. The first is Piaget's preoccupation with epistemology. Structures are excellent building-block in '*the reconstruction of the Kantian a priori categories of Knowledge as developmental necessities*'. (Wallace 1976, page 117) The second factor is the adoption in his main work on groupings of a type of mathematical formalisation. In addition, Piaget's experiments were concerned with '*logical thinking in the strict sense*' and required the subjects to make distinctions between logically valid and fallacious arguments (Wallace, 1976).

In general, the experimental evidence indicates that principles, such as conservation, are successfully applied at different times to different concepts and to different test situations representing the same concept. Moreover, Egan (1983) argues that Piaget claims that his theory describes a natural process whereby some aspects of cognition develop: it answers such questions as "*What conception of the world does the child naturally form at the different stages of its development?*' (Egan, 1983) As our bodies develop naturally in a certain typical pattern if they have adequate food, exercise, and so on, so the part of our cognition which Piaget's theory describes follows a regular pattern if it has adequate interactions with social, physical, and cultural environments.

2.4 The Four Piagetian Concepts

Wadsworth (1984) noted the four key concepts which Piaget found so useful in describing what he observed. These are illustrated in table 2.3. Each is discussed in turn.

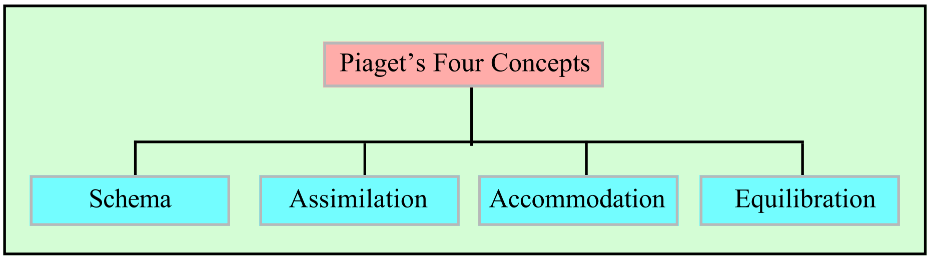


Table 2.3 Piaget's Four Concepts

(1) *Schema:* Piaget believed that the mind has structures much in the same way that the body does. As structures, schemata (the plural of *schema*) are the mental counterparts of biological means of adapting. Schemata can be also simplistically thought of as concepts or categories and used to process and identify incoming stimuli. In addition, when a child is born, it has few schemata already developed. As the child develops, the schemata gradually become more generalised, more differentiated and progressively more 'adult'. Since schemata are structures of cognitive development that do change, allowance must be made for their growth and development. The cognitive schemata of the adult are derived from the sensori-motor schemata of the child. The processes responsible for the change are assimilation and accommodation. Flavell (1963, page 52) also says '*assimilatory and accommodatory functioning always presupposes some sort of quasi-enduring organisation or structural system within the organism*'. He also asserts that Piaget strongly emphasises the role of corrective experience in the construction and transformation of schemes.

(2) *Assimilation:* Wadsworth (1984) indicates that assimilation is the cognitive process by which a person integrates new perceptual, motor or conceptual matter into existing schemata or patterns of behaviour. In addition, assimilation theoretically does not result in a change of schemata but it does affect the growth of schemata and is thus a part of development. The process of assimilation allows for the growth of schemata. Adult schemata are different from those of children. Piaget accounted for the change of schemata with accommodation. Likewise, Flavell (1963) pointed out

that assimilation here refers to fact that every cognitive encounter with an environmental object necessarily involves some kind of cognitive structuring (or restructuring) of that object in accord with the nature of the organism's existing intellectual organisation. Moreover, Paiget (1952) indicates assimilation can never be pure because by incorporating new elements into its earlier schemata, the intelligence constantly modifies the latter in order to adjust them to new elements. Conversely, things are never known by themselves since this work of accommodation is only possible as a function of the inverse process of assimilation.

(3) *Accommodation:* Accommodation is the creation of new schemata or the modification of old schemata. Both actions result in a change in, or development of, cognitive structures (schemata). Schemata reflect the child's current level of understanding and knowledge of the world. Yet, Flavell (1963) observes that accommodation of mental structures to reality implies the existence of assimilatory schemata apart from which any structure would be impossible. Inversely, the '*formation of schemata through assimilation entails the utilisation of external realities to which the former must accommodate, however crudely*' **(**Flavell 1963, page 49**)**. However, Flavell (1963) points out that assimilation and accommodation are obviously opposed to one another, since assimilation is conservative and tends to subordinate the environment to the organism as it is, whereas accommodation is the source of changes and bends the organism to the successive constraints of the environment.

(4) *Equilibration:* The processes of assimilation and accommodation are necessary for cognitive growth and development. Piaget called the balance between assimilation and accommodation as equilibration. It is necessary to ensure the developing child's efficient interaction with the environment. Moreover, if the child cannot assimilate the stimulus, he or she then attempts to accommodate by modifying a schema, or the stimulus proceeds,and equilibrium is reached for the moment.

2.5 The Upper Two Stages

Traditionally, the science subjects were reserved to the secondary school levels of education (approximately ages 12 onwards) and science in any recognisable form was not taught at primary stages although pupils did have opportunities for biological observations with plants and animals like frogs and fish. Thus, early Scottish syllabuses assumed little or no science background on entry to secondary (see Circulars 490 and 512). Later, formal science was introduced into the primary stages, often with considerable disquiet from teachers who lacked any background or confidence (see Harlen and Holroyd, 1995). A typical science input into primary stages can be seen in the Scottish 5-14 Guidelines (2000). The reasons for the change rarely addressed the issue of cognitive development and most curriculum documents assumed it was a good thing to do, with no regard for any evidence relating to its appropriateness or otherwise.

In the last four years of primary education children are moving through Piaget's stage of concrete operations before developing formal operational thought. The early years of secondary will tend to see the young person moving through the development of formal operations. The hypothetical can be conceptualised. These two stages of education are critical in that the sciences are often introduced at primary stages and then built upon in the early secondary years before the student begins to think of subject choice for future study. If the science to be taught is inappropriate for the stage, then considerable damage may be done to the learner, the result of which might be that they reject the further study of the sciences. These two stages of Piaget's analysis are now considered in more detail.

2.5.1 The Stage of Concrete Operations

Wadsworth (1984) asserts that the concrete operational child de-centres his or her perception and attends to transformations. This can be illustrated by looking at time and velocity. Wadsworth (1984, page 103) notes that Piaget and Inhelder contended that children typically do not understand the relationship between time, distance travelled and speed [speed = distance / time] until age 10 or 11.

Consider the following: two cars leave point A (Figure 2.1) at the same time. They both arrive at B at the same time, but they traverse different routes (1 and 2). After viewing this problem, observing the movement of the cars, the pre operational child reports that both cars travelled at the same speed. Not until age 8 or so does a ratio concept of speed in terms of the relationship between time and distance travelled begin to evolve.

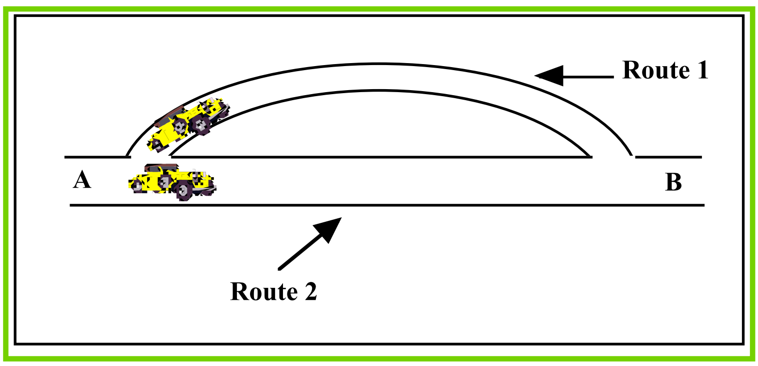


Figure 2.1 The Two Car Problem

Sutherland (1982), investigating the age of attainment across the whole school age-range of various concepts, found that both biology and physical science pupils in a comprehensive school understood respiration and the water cycle in formal operational terms only at the age of 16. Shayer *et al*., (1976) and Shayer and Wylan (1978) had similar findings with representative samples of school-age pupils in England. McNally (1970), working at more or less the same time in Australia, also had similar results. This suggests that formal operational thought, while it may develop from age 12, did not seem to be fully operational until nearer 16.

In a similar way, Sutherland (1982) found that concrete operations were attained only at an average age of 12. Shayer *et al*., (1976) found the same thing. It seems that pupils, on average, only attain concrete operations fully in the first year of secondary school. However, as Bryant (1972) and Donaldson (1978) found, concrete operations in different areas were being attained at much younger ages than Piaget found.

These findings illustrate that the neat age-stage model of Piaget is, perhaps, much too precise. However, they illustrate the full achievement of a Piagetian stage may not occur until nearer the upper limit of age as suggested by Piaget. Indeed, if the learner has not needed to employ more advanced cognitive strategies, (s)he may not demonstrate the cognitive behaviour at all.

2.5.2 The Stage of Formal Operations

Wadsworth (1984) argues that, during the stage of formal operations, which occurs around age 11 - 15 or older, a child develops the reasoning and logic to solve all classes of problems. There is a freeing of thought from direct experience. The child's cognitive structures move slowly towards maturity during this stage. Assimilation and accommodation, prompted by disequilibrium continue through life to produce changes in schemata.

Furthermore, Wadsworth (1984) considers that the *quality* of reasoning one is capable of does not improve after this stage. This does not mean that the use of thought cannot or does not improve after adolescence. The *content and function* of thought are free to vary and improve after this stage, which in part helps explain some of the classical differences between adolescent thought and adult thought.

In order to understand Piaget's theoretical and experimental attack on perceptual problems, it is absolutely essential to understand his conception of perception as a mode of adaptation (Flavell, 1963). He has definite ideas and the main essentials of these ideas can be expressed in three related beliefs:

(1) Intelligence and perception need to be sharply distinguished as types of adaptation.

(2) The emphasis on sharp differentiation and the objection to promiscuous use of the term perception give the clue to the second, related belief: for Piaget perception covers a narrower, more restricted range of behaviours than it does for most.

(3) Piaget believes that perception arises developmentally, not as an autonomous mode of adaptation in its own right, but as a kind of dependent subsystem within the larger context of an evolving sensory-motor intelligence.

Piaget's concept of formal operational thought has been very useful in both psychology and education.

Piaget's formal operational thinking is hypothetico-deductive. The adolescent can conceive of a new idea, try it out in his head and then test it. Thus, deduction can be employed at this stage. The young teenager starts to be able to deduce an implication from a general principle. This means that, in physics, formulae can be understood and applied. In mathematics, a follow-up proposition can be deduced from a general proposition. In addition, the adolescent becomes capable of drawing the necessary conclusions from truths which are merely possible.

In general, the formal operational thinker is much better at organising and structuring the elements of a problem than a concrete operational thinker.

In formal operations, various elements in a problem interact with each other. For example is the hydraulic press, as shown in the figure below (2.2), the intuitive thinker knows the left-hand side will go down under the weight and the right side will go up. The concrete operational thinker adds the compensatory element: the left side is wider than the right, so the left will sink less than the right will rise. However, the formal operational thinker can actually calculate the distances the liquid will move up or down the cylinder using the appropriate formula (assuming that the principles have been taught).

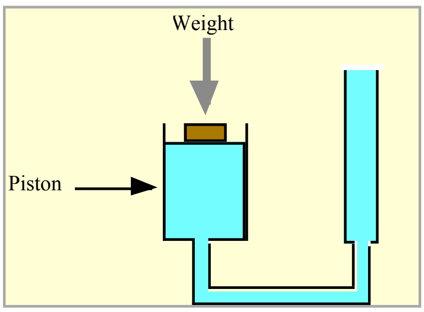


Figure 2.2 An illustration of formal operational thinking (Derived from Sutherland, 1992, page 22)

In addition, Raja (1992) indicates that, during this stage, the person's cognitive structures reach their greatest level of development and the ability to apply logical reasoning to all classes of problems is being developed.

2.6 Cognitive Development and Adolescence

While Piaget did not attempt to explain all adolescent behaviour, he did provide an important link between cognitive development, affective development, and general behaviour. Wadsworth (1984) states that the development of cognitive structures before and during adolescence helps account for the characteristics of behaviour during the period. Piaget believed that the characteristics of adolescent thought that make the adolescent unique are in part due to the child's level of cognitive development and his or her accompanying egocentrism of thought.

Wadsworth (1984) implies that, during concrete operations (7-11 years), a child starts to develop the ability to apply logical operations to concrete problems. In addition, in adolescent thought, the criterion for making judgements becomes what is logical to the adolescent, as if what is logical in the eyes of the adolescent is always right, and what is illogical is always wrong. The adolescent is emboldened with an egocentric belief in the omnipotence of logical thought. Because the adolescent young person can think logically about the future and about hypothetical people and events, (s)he feels that the world should submit itself to logical schemes rather than to systems of reality. He does not understand that the world is not always logically or rationally ordered. Moreover, the stage of formal operations, which usually begins around age 12 and is complete at age 16 or later, builds upon, incorporates, and extends the development of concrete operations.

Gallagher and Reid (1981) argue that not all adolescents and adults develop fully formal operations, but according to Piaget, all normal people have the potential to do so. In addition, Flavell (1963) explain that the adolescent can deal effectively with the reality. This kind of cognition, for which Piaget finds considerable evidence in his adolescent subjects, is adult thought in the sense that these are the structures within which adults operate when they are at their cognitive best: when they are thinking logically and abstractly.

2.7 Development and Learning.

Wadsworth (1984) asserts that development and learning have similarities and differences. Intellectual, or cognitive, development is the process of growth of intellectual structures. It is viewed as a process of construction. The interaction of maturation, experience, social interaction, and equilibration are all important. They are all part of development. For Piagetians, learning always involves construction and comprehension.

In addition, Egan (1983) notes that the fundamental cognitive processes, whose development Piaget claims to describe, are expressed in terms of logico-mathematical structures. These are '*the natural psychological reality, in terms of which we must understand the development of knowledge*'. He also says that Piaget claims that '*learning is subordinate to the subject's level of development*', that no sort of learning is possible without logic-mathematical frameworks: '*that teaching children concepts that they have not attained in their spontaneous development is completely hopeless*', that teaching must be 's*ubordinated to spontaneous and psychological development*'.

In addition, he asserts that Piaget accepts that experience, environment, and social interactions will all affect the rate at which people develop these underlying structures, and will affect the extent to which the development will occur. However, Egan (1983) points out that '*one obvious use of the theory would be as a guide to the teacher in knowing what and how to teach children at any particular age*'. The task of the teacher is to figure out what the learner already knows and how he reasons in order to ask the right question at the right time so that the learner can build his knowledge of the developmental stages, and the theory of the developmental process.

2.8 The Criticisms of Piaget

Although criticism of Piaget started with Vygotsky in the 1920s, was continued by Bruner in the 1960s, the 1970s and 1980s saw criticisms develop (Sutherland, 1992) Nonetheless, Piagetians will argue that Piaget still provides the most powerful explanatory theory for developmental changes we have.

Egan (1983, page 62) notes that the extreme case against Piaget is the claim that what he is measuring is not the development of cognitive structures but simply children's growing mastery of semantic rules that relate to the Piagetian tasks. In addition, Ausubel *et al*., (1980) make many comments on the work of Piaget. They note that the transition between the stages Piaget describes occurs more gradually than Piaget suggests. They also note that the ages for transitions may vary from child to child and, indeed, from culture to culture. Indeed, environmental factors can have an influence on cognitive development. It has been noted that a child can operate at one level in one context but at another in a different context and that Piaget's model does not take account of individual differences (see: Bandura and Walters, 1963b). Hall and Lindsey (1957) consider such criticism unfair in that Piaget's model does not preclude individual differences.

Overall, many (eg. Ausubel, 1958, 1980 *et al*; Brainerd, 1979; Flavell and Wohlwill, 1969) have expressed concern over the validity of Piaget's stages. Ausubel *et al*., (1980, p.71) reviews the views of American psychologists and summarises their views:

> '*(1) The transitions between these stages occur gradually rather than abruptly or discontinuously.*
> *(2) Variability exists both between different cultures and within a given culture with respect to the age at which the transition takes place.*
> *(3) Fluctuations occur over time in the level of cognitive functioning manifested by a given child.*
> *(4) The transition to the abstract stage occurs at different ages both for different subject matter fields and for component subdivisions within a particular field.*
> *(5) Later stages of development are not found in certain cultures or particular individuals within a culture.*
> *(6) Environmental as well as endogenous factors have a demonstrable influence on the rate of cognitive development.*'

Although it is also possible to consider that language development may be partly responsible for what Piaget described, Piaget did give an account of what he observed and many of his observations can be repeated. He did not attempt to look at individual differences and, perhaps, his transitions were seen in too an abrupt and overarching way. He overemphasised the biological development and tended to ignore cultural and social factors. This was developed by Vygotsky (1978).

Despite all this, Piaget brought great insights into the whole area of cognitive development. He established the idea that children do not necessarily think as 'miniature' adults. He also established that the learner is seeking to make sense of the world they encounter and that the conclusions drawn may not always be valid.

Brunner argued that teachers should encourage their pupils to move forward rapidly, thus implying that it was possible to accelerate children through the Piagetian stages of development (cited in Sutherland, 1992, p.58)

Bruner argues that language is one of the main weapons for acceleration while lessons must be presented in such a way as to stimulate pupils interest. However, Piaget did emphasise environmental factors, noting the need for the physical environment to be as stimulating as possible so that the child wants to learn from it. Nonetheless, Bruner criticised Piaget's failure to take account of the child's previous experiences, a point noted by Ausubel *et al*., (1968).

Serumola (2003) noted that one of the major criticisms levelled against Piaget was the rigidity of the boundaries he used to define the developmental stages of knowledge construction. It does appear that, while the child does move through these stages, the boundaries are much less defined than was first thought.

Another criticism on Piaget's theory is levelled at his method of data collection (Flavell, 1963). The controversy stems from the use of an unsystematic methods. He used a statistically small sample to collect data and he is, therefore, accused of not considering the importance attached to the significance and reliability of the data collect on the validity of his conclusions. However, much of this is not totally valid criticism. Piaget used children as case studies, forming his model of developmental learning from his detailed observations. Piaget described what he saw; he did not attempt to explain it (Raja, 1992).

Yang (2000) also indicates that the critics of Piaget had noted his boundaries were far too rigid. and his conclusions based on poor sampling. It does appear that the child's experience and environment are far more powerful influence on their cognitive development than Piaget allowed (Bruner, 1996).

Recently, Bliss (1995) offers three challenges to Piaget in relation to science education which are summarised here:

(a) He notes that some are arguing that the formal operational stage does not describe appropriately the thinking and reasoning of most secondary school pupils;
(b) At any stage, there is the importance of the context. Some will be working at formal operations level in one context but not in another;
(c) There is a strong awareness of the importance of the socio-cultural context of learning. Learning cannot be seen as some abstract activity; it takes place in a social context.

Fox (1994) reported two critical issues in relation to Piaget's model. Firstly, Piaget believed that it is the cognitive structure which changes first and the language development just stems from the changes in cognitive development. The second issue is whether the four stage are an accurate reflection of children's cognitive development.

2.9 Conclusions

However, although many criticisms emerged, Piaget still has to be considered as one of the outstanding cognitive and developmental psychologist of all time. By means of careful observation, he demonstrated that there is a developmental aspect to learning: children are not simply 'very small adults'. He also showed very clearly that the learner is exploring the environment seeking to make sense of what is seen, heard, touched or smelled. This process of seeking to make sense of things is extremely important in that it suggests that the natural aim of learning is the attempt to understand. This is very different when compared to the emphasis on remembering and recall which characterises so much education today.

Chapter Three

Cognitive Development
Further Contributions

3.1 Introduction

Piaget's great contribution was that, as a result of careful observation, it became clear that intellectual development was occurring as the child grew up. Of greatest importance was the insight that cognitive structures and ways of thinking grew with age: thus, the child does not think in the same way as the adult and education has to take account of this developmental process in structuring programmes of learning.

This chapter explores the way the ideas of Piaget influenced later researchers and seeks to offer an insight into the way their findings can influence thinking about developmental aspects of learning. In all of this, the focus is on learning in science-mathematics areas of the curriculum.

3.2 Ausubel's Underlying Ideas

David Ausubel was an American psychologist (born 1918) who was very influenced by the teachings of Jean Piaget. Ausubel and Robinson (1969, page 37) suggested that there were two groups of cognitive variables influencing learning:

> '(1) *Cognitive structure variables*: substantive and organisational properties of previously acquired knowledge in a particular subject matter field that are relevant for the assimilation of another learning task in the same field.
>
> (2) *Developmental readiness*: the particular kind of readiness that reflects the learner's stage of intellectual development and the intellectual capacities and modes of intellectual functioning characteristic of that stage. The cognitive equipment of the fifteen year old learner obviously makes him ready for different kinds of learning tasks than does that of the six or ten year old learner.'

In simple terms, what the person knew already and how they had come to that knowledge along with developmental readiness for learning, were the two strong controlling factors on subsequent learning.

3.3 The Idea of Education Theory

The word 'theory' carries within it a variety of meanings. For example, the word is sometimes used in a scientific sense to mean an hypothesis or it can mean the best rationalisation of observed data. However, the word is often used very loosely and sometimes it suggests ideas which are more like a speculation. Unfortunately, this range of meanings can carry over into educational thinking. The word is being used here in the sense of the best rationalisation or description which fits or accounts for data and, in that sense, is more like the hypothesis of formal science.

Educational theories seek to offer such descriptions or hypotheses which take account of observed data (Ausubel and Robinson, 1969). Such statements or models represent the best attempts to account for what has been measured in some way. Educational theories tends to concentrate on schools. This is because it is here that there is the greatest opportunity to systematically manipulate the educational environment variables ('independent' variables) and observe the outcomes ('dependent' variables).

3.4 Meaningful Learning

Ausubel and Robinson (1969) brought much needed clarity to an often confused area when they separated rote-meaningful learning from reception-discovery learning, seeing them as two completely unrelated dimensions (see Figure 3.1).

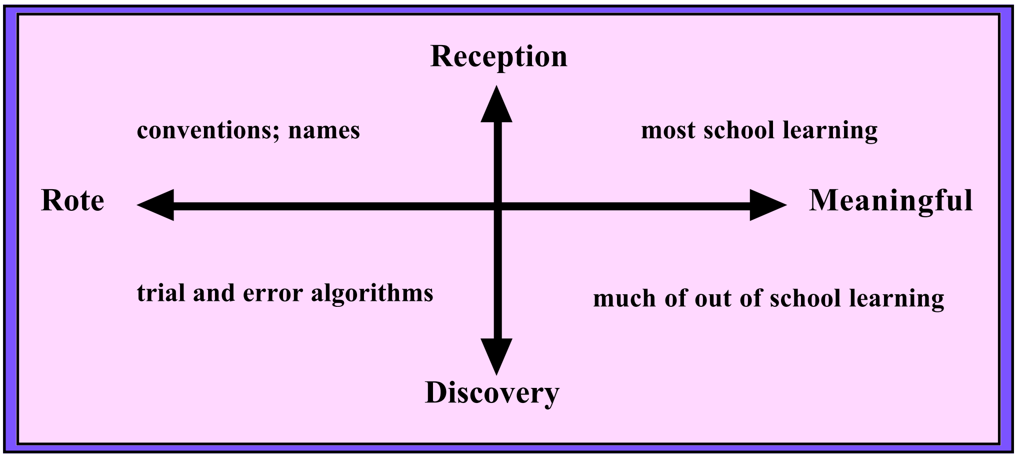


Figure 3.1 Dimensions of Learning (derived from Ausubel at al, 1969)

Ausubel and Robinson (1969) indicate that the essential feature of discovery learning is that the principal content of what is to be learned is not given but must be discovered by the learner before it can be meaningfully incorporated into the student's cognitive structure. Discovery learning is commonly used in the classroom both to apply or extend ideas, to clarify, integrate or evaluate subject-matter. Discovery, in a school setting, is usually not independent discovery on the part of the learner. While the principal content of what is to be learned is not given in its final form but must be discovered by the learner, the teacher may well employ a form of 'guided' discovery. Thus, the teacher knows the outcomes desired but allows the learners to make the discoveries for themselves, setting the learners off on the road to discovery.

Reception learning is the opposite in that the teacher presents what is to be learned in its final form, the material being organised and made available to the learner. This requires the learner to relate the new material to existing ideas in some sensible fashion. Of course, much learning, whether reception or discovery can end up not being related to previous knowledge and can hardly be described as meaningful. This is where Ausubel's second dimensions comes in: rote-meaningful.

With rote learning, new ideas are memorised and not linked on to previous knowledge and experience in any meaningful way while meaningful learning implies that the new knowledge is linked to previous knowledge, enriching both.

Meaningful discovery learning will occur if the student formulates the generalisation himself and subsequently relates it in a sensible way to his existing ideas. Rote discovery learning could occur if the learner, having arrived at the generalisation himself (typically by trial and error), subsequently commits it to memory without relating it to other relevant ideas in his cognitive structure. Of course, there is also reception-rote learning and reception meaningful learning. Ausubel also makes it clear that the point which is necessary for meaningful learning is that the relationship between the new item to be learned and relevant items in cognitive structure be non arbitrary.

Logical meaningfulness is clearly a property of the material to be learned and is not sufficient to guarantee that it will be meaningful to the learner. Thus, meaningful learning requires that these three conditions hold below:

'*(a) The material itself must be relatable to some hypothetical cognitive structure in a non-arbitrary and substantive fashion.*
(b) The learner must possess relevant ideas to which to relate the material.
(c) The learner must possess the intent to relate these ideas to cognitive structure in a non arbitrary and substantive fashion.' (Ausubel, 1968, page 53)

Very often, reception learning is seen as rote and the discovery learning is presented as inherently and necessarily meaningful. Both assumptions, of course, reflect the long-standing belief in many educational circles that the only knowledge one really possesses and understands is knowledge that one discovers by oneself and this is, of course, not true (see Ausubel *et al.,* 1978). The key idea is the separation of the two dimensions and this can be illustrated in figure 3.2

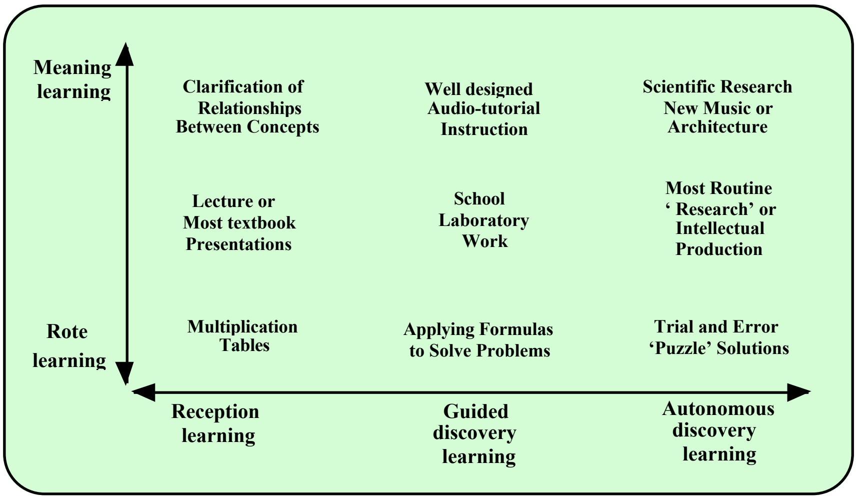


Figure 3.2 : ***Reception Learning and Discovery Learning*** **(Source: Wandersee & Novak, 1998)**

Ausubel *et al.,* (1978, page 39) suggest that the meaningful reception learning is important in education because it is ‘*the human mechanism par excellence for acquiring and storing the vast quantity of ideas and information represented by any field of knowledge*’. Thus, Ausubel stresses the importance of reception learning in formal school situations, seeing discovery learning as much less important.

Ausubel and Robinson (1969) consider the observations of Piaget (Piaget, 1950; Uzgaris, 1964) that there is an emergence of the conservation of mass, weight, number, and volume in that order and interpret this in terms of an increasing ability to manipulate images. They see this as the child acquiring what they call ‘secondary abstraction’ and that this means the child can mentally manipulate abstractions and relations between abstractions. However, Piaget sees this stage in terms of concrete operations where the child is able to handle things that can be seen and touched. Indeed, the evidence suggests that the child essentially understands and manipulates relations between the verbal representations of secondary abstractions.

Looking at the abstract stage, Ausubel *et al*., (1978) argue that, from the age when students enter junior high school (about age 12), the pupil becomes increasingly less dependent upon the availability of concrete-empirical props in meaningfully relating abstract relationships to cognitive structure. The pupil starts to develop the ability to take in abstract propositions and solve abstract problems. The pupil also starts to develop the possibility of being able deal with all inclusive hypothetical possibilities rather than being limited to possibilities which are constrained by what can be seen and experienced directly (Piaget, 1957).

3.5 Development and Intelligence

Ausubel and Robinson (1969) asserts strongly that intelligence tests cannot measure intellectual capacity and that they do not claim to do so. Any intelligence test measures ability to perform the kinds of tasks set within the test, at the time the test is given. Abilities may change with time. If intelligence is to be seen in terms of some kind of capacity, any test of ability made at one point of time may offer some kind estimate of capacity. However, the match between demonstrated ability at one moment of time and intellectual capacity will only be very approximate.

Ausubel *et al*., (1978) argue that general theories of intellectual development, such as those advanced by Piaget and his collaborators (Inhelder and Piaget, 1958; Piaget, 1950, 1954), include age-level changes. These changes occur in at least four major areas of cognitive functioning: perception, objectivity-subjectivity, the structure of ideas or knowledge, and the nature of thinking or problem solving. The older child is more capable of viewing situations from a hypothetical ('as if') basis or from the standpoint of others (Baker, 1942; Piaget, 1928, 1929).

If intelligence is to be seen in terms of capacity, then any developmental understanding of learning is something very distinct from any concept of intelligence. Children develop at different rates (although they seem to go through the same developmental stages). The fact that a young person has the capability of functioning at a given developmental level is no guarantee that they will demonstrate this ability in any test. The work of Heron (1975) shows that even university students may not be functioning at a formal operations level in all areas of knowledge. Much depends on opportunities given to the learner to demonstrate and apply their inbuilt capabilities. This has clear cultural as well as educational influences. Thus, if the way teaching, learning and assessment are arranged does not encourage or give opportunities for the application of formal thinking , then the learner may will not demonstrate such thinking.

Overall, given appropriate opportunities, there is a gradual shift from concrete to abstract cognitive functioning as the young person moves from the world of primary education and into the early years of secondary education. Bruner (1972) argues that this defines the principal differences between the respective learning and thinking processes of primary and secondary school pupils as well as the corresponding differences in pedagogic strategy that they imply. Intelligence is to be seen as latent capability which may or may not be demonstrated in test performance at a specific age.

The key feature of cognitive development from the perspective of this study is the observation from the work of Piaget that the older child is more capable of viewing situations from a hypothetical ('as if') basis or from the standpoint of others. This is critical when thinking of scientific thinking with its fundamental emphasis on the hypothesis. If a person is cognitively not able to think in terms of hypotheses (whatever language is used to describe these), then it is likely that true scientific thinking is not an option. Ausubel *et al*., (1978) accept the very different thinking processes which start to develop in early secondary years (ages 12-16) and emphasise that very different pedagogic strategies are needed for secondary students. There will be considerable implications from this for the teaching of the sciences at primary stages and at secondary stages. *et al*.,

3.6 The Development of Thinking

In looking at thinking and more specifically at skills which might be called critical thinking, Ausubel and Robinson (1969) described some instructional materials which had been developed in the past. They aimed to develop critical-thinking abilities and the materials tried to help the teachers to achieve this aim. However, they noted that wide differences were found among teachers with respect to improvement of their students in critical thinking (Smith, 1960). They found that it was very difficult to draw clear conclusions. The main reasons was that there was little agreement on what was being attempted. The problem of describing (little less defining) something like critical thinking was immense. They noted the need to devise a method of categorising the logical operations involved in teaching critical thinking. In this, they are clear that they are not talking about teaching logic as a discipline. They are seeing the teaching of critical thinking as integral to subject teaching. It is possible that scientific thinking can be seen as a form of critical thinking which is appropriate to the subject areas which are known as the sciences. This will be pursued later in this study.

Their approach raises some interesting questions. If it can be assumed that the capacity to think critically is dependent on the development of formal operational thinking in some way, then it is possible that critical thinking ability is simply a function of age and development. This might imply that teaching has no place. On the other hand, students may well not demonstrate this kind of thinking unless they are given opportunities to apply it in ways which are meaningful and perceived to be helpful. To what extent is the giving of opportunities to demonstrate a kind of thinking to be seen as teaching? Perhaps, there is a need for overt teaching where the teacher is able to show the value and nature of such thinking while giving the opportunities for students to develop the skills in a way that suits their cognitive development as well as the way such thinking skills build up logically. There is another important issue which can be raised. If the assessment system in education does not reward the use of any kind of critical thinking, then there is no incentive for students to think this way. In end, the nature of the assessment system may prove critical.

Ausubel and Robinson (1969) consider that the conventional distinctions between induction and deduction tend to be somewhat misleading. The distinctions seem to imply a sense of opposition. Inductive thinking refers to the situation found most frequently in problems open to scientific experimentation in which the experimenter moves in thought from particular instances to a general statement of principle. Deduction is usually considered to be the reverse process: here the work proceeds from the general principle to the specific conclusion. Both might be seen as related to scientific thinking.

They argue that the two processes, induction and deduction, cannot be so neatly separated in most problem-solving situations. For example, in looking at ways to understand how a pendulum works, the child may be said to reason inductively from particular instances to the general proposition that weight of the pendulum bob does not influence its period. Nonetheless, the processes of induction are often caught up with a general strategy which is overtly deductive.

Thus, the process might be seen as:

Hypothesis: The weight of the bob is a factor influencing the period of the pendulum.

Deduction: If the hypothesis is true, changing the weight of the bob should change the period of the pendulum.

Induction: Changing the weight of the bob does not change the period of the pendulum.

Deduction: Weight (of bob) is not a causal factor.

This illustrates the problem of trying to reduce cognitive process to sets of categories. In real life, individuals do notwork in such neat ways.

Similar comments can be made concerning the distinction between convergent and divergent approaches to problem solving. In most instances the typical sequence of operations involves the generation of multiple hypotheses or courses of action (divergent thinking) followed by the gradual elimination of those hypotheses that are untenable (convergent thinking).

Ausubel *et al*., (1978) noted several attempts to enhance critical-thinking ability by influencing cognitive structure in particular subject matter areas (eg. Abercrombie, 1960; Novak, 1958; Smith, 1960). Thus, Novak found that a six-week experience in problem solving in botany did not increase problem-solving ability as he measured it.

Moreover, Ausubel and Robinson (1969) developed a suggested relationship between application, problem solving and creativity as shows in figure 3.3:

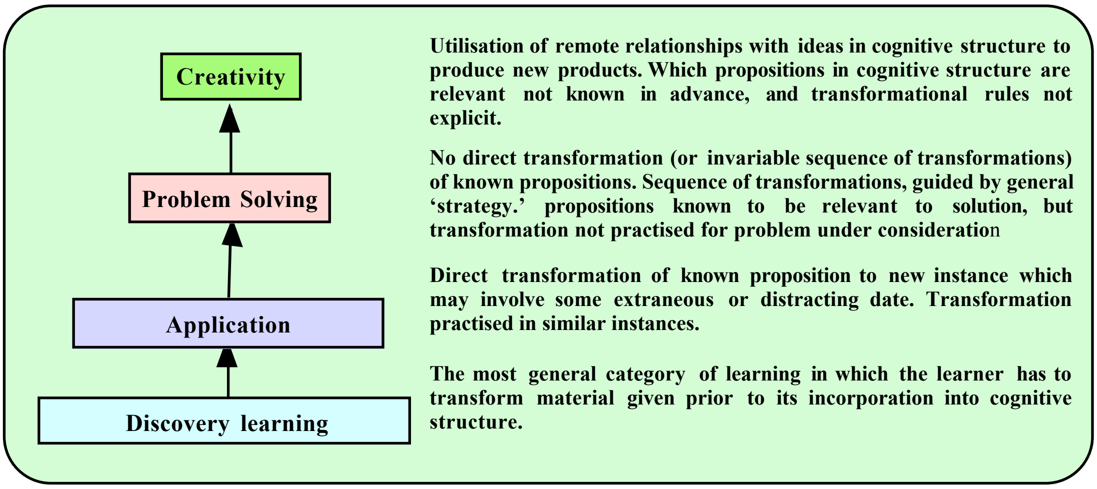


Figure 3.3 Problem Solving and Creativity
(derived from Ausubel and Robinson, 1969, page 72)

Ausubel has made many major contributions to the understanding of learning which exists today. In particular, he clarified the nature of meaningful and rote learning as separate dimensions from the style of teaching. Of even greater importance for this study is his insight into the importance of prior learning on future understanding. This will have major implications for scientific thinking where experience and ways of thought which have developed during prior learning will enable the student to think scientifically or, perhaps, not to think in this way.

3.7 An Overview of the Work of Bruner

Bruner (1969) made considerable contributions to cognitive psychology and cognitive learning theory in educational psychology and is probably best known for his ideas on discovery learning. However, his work offers some useful insights into developmental aspects of learning and he often considered learning in the mathematics-sciences areas of the curriculum.

Bruner's ideas are based on categorisation: "To perceive is to categorise, to conceptualise is to categorise, to learn is to form categories, to make decisions is to categorise." Wikipedia (2007)). Bruner argues that people interpret the world in terms of its similarities and differences. Like Bloom's Taxonomy (Bloom and Krathwohl, 1956), Bruner suggested a system of coding in which people form a hierarchical arrangement of related categories. Each successively higher level of categories becomes more specific, echoing Bloom's understanding of knowledge acquisition as well as the related idea of instructional scaffolding (Anderson *et al.*, 2001).

Bruner (1986) was acutely aware of the place of language in learning in that this offers a symbolic environment and how the learner works within it. Thus, language is a critical tool which enables learning to occur as well as determining to some extent what does occur. Bruner (1986) also noted the genuine and significant differences between the arts and the sciences which he saw in terms of their common cognitive function. Since both the science and the arts consist very largely in the processing of symbols, an analysis and classification of types of symbol systems provides an indispensable theoretical background for them both.

Looking more specifically at developmental aspects, Bruner (1986) proposed that what is most important for teaching basic concepts is that the child be helped to pass progressively from concrete thinking to the utilisation of more conceptually adequate modes of thought. However, the intellectual development of the child is also influenced by the environment. In formal education, this means mainly the school environment. In considering a subject like physics, Bruner (1969) notes the way understandings are constructed. This can be seen as almost constructing a mental world to mirror reality, and then testing the real world against the ideas.

However, Bruner (1969) stresses that, in order for a person to be able to recognise the applicability or inapplicability of an idea to a new situation, thus broadening learning, the person must have clearly in mind the general nature of the phenomenon with which he is dealing. The more fundamental is the idea which has been grasped, the greater will be its breadth of applicability to new problems. Thus, understanding fundamentals makes a subject more comprehensible. There is a distinction between doing and understanding. Thus, a learner may be able to solve the equation or use the algorithm correctly but not understand what is happening. Equally, the reverse may occur. Achieving both must be the aim.

Bruner (1996) assumes that children, like adults, are to be seen as constructing a model of the world to aid them in understanding their experience. Up until the concrete operational stage, the child's learning can be seen as active. In the concrete operational stage, the data form the real work is worked on so that it can be organised and used selectively in the solution of problems (P.18-38). He considers that young children learn almost anything faster than adults do if what is to be learned can be given to them in terms they can understand. He values the place of discussion and collaboration, with the child encouraged to express her own views better to achieve some meeting of minds with others who may have other views.

In the light of this, Bruner (1996) proposed that pupils should be presented with facts, principles, and rules of action which are to be learned, remembered, and then applied. Thus, for example, in algebra, there are three fundamentals: commutation, distribution,and association. Once a student grasps the ideas underlying these three fundamentals, he is in a position to apply these in solving equations where the task is to make the unknown take on value. This sounds nice but it implies that the learner is capable of handling such abstractions. In practice, mathematics teachers make the learner practice procedures so many times that they are being applied almost automatically to solve equations. Textbooks offer sets of exercises for that purpose. With the confidence arising from successful achievement, the learner is now at the stage of being able to consider the meaning of what has been undertaken. This is the very opposite of what Bruner suggests.

Bruner values transfer of learning highly, arguing that transfer is at the heart of the educational process. This means the continual broadening and deepening of knowledge in terms of basic and general ideas (P.8-55). He is arguing that all learning should offer ideas and understandings which are then able to be extended or applied more widely. There is no doubt that this is a desirable goal. However, the whole area of transfer of learning has been challenged recently when problem solving skills were found to be highly context dependent (see Reid and Yang, 2002b; Al-Qasmi, 2006).

Sutherland (1992) notes that Bruner's ideas have similarities with Vygotsky with both emphasise an interventionist role for teachers. Both Bruner and Vygotsky argue against the view of Piaget that a teacher has to wait until a pupil is intellectually ready before he can be taught any particular topic. However, Bruner has a child-centred approach to the task, with children should be set tasks by teachers and encouraged to discover truths for themselves. Vygotsky, on the other hand, urged a teacher-centred approach with direct instruction.

3.8 The Contribution of Vygotsky

Vygotsky was born in Belorussia to a middle-class Jewish family in 1896 and was a Russian developmental psychologist and philosopher. He died of tuberculosis at the age of 37 in 1934 and his work was suppressed and did not become widely known outside the former Soviet Union until the reprinting of 'Thought and Language' in 1962 (see: Kozulin, 1997; Carrol, 2005).

Vygotsky suggested that understandings of cognitive development must be built upon three concepts: higher mental functions, cultural development, and self-mastery of behavioural processes. Vygotsky described 'pseudo-conceptual thinking': a child's reasoning that coincides with reasoning in adult and yet has a different, pre-conceptual nature (Kozulin, 1997).

Rieber and Robinson (2004) note that both Piaget and Vygotsky discuss linguistic forms and agree that they are equally socialised. However, they approach language development somewhat differently, with language seen as the precursor to cognitive development by Vygotsky. Kozulin (1999) discusses the way Vygotsky saw language and cognitive development as two developmental lines which become intertwined. Thus, thought becomes verbal; and speech is intellectual.

Blunden (2001) notes the emphasis of Piaget that *development leads learning*: children can only learn what is possible for their given stage of development, this coming from innate development. Vygotsky on the contrary, held that *learning leads development*: being presented with challenges and overcoming these challenges, with appropriate help, *induces* the development of new abilities. Thus, Vygotsky's school is based on *collaborative problem solving*.

Vygotsky viewed cognitive developments as a result of a process where the child learns through problem-solving experiences shared with someone else, such as parents, teacher, siblings or a peer. Originally, the person interacting with the child undertakes most of the responsibility for guiding the problem solving, but gradually this responsibility transfers to the child (Kristinsdótti, 2007).

Vygotsky´s understanding is, firstly, very much that of gradual internalisation, primarily through language, to form cultural adaptation (Rogoff, 1990). Secondly, there is the idea that the potential for cognitive development is limited to a certain time span which he calls the '*zone of proximal development*' (ZPD). ZPD refers to the gap between what a given child can achieve alone, their 'potential development as determined by independent problem solving', and what they can achieve 'through problem solving under adult guidance or in collaboration with more capable peers' (Wood and Wood, 1966).

Thus, the difference between twelve and eight or between nine and eight years, is what is called the Zone of Proximal Development. It is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. The Zone of Proximal Development defines those function that have not yet matured but are in the process of maturation, functions that will mature tomorrow but are currently in an embryonic state. He argued that the developmental processes do not coincide with learning processes. Rather, the developmental process lags behind the learning process; this sequence then results in Zones of Proximal Development (Vygotsky, 1978).

It can be seen that, if a learning is being extended (in the concept of Zone of Proximal Development), then there are similarities with pure imitation. However, the two are not the same. For example, if a child is having difficulty with a problem in arithmetic and the teacher solves it on the blackboard, the child may grasp the solution in an instant. However, if the teacher were to solve a problem in higher mathematics, the child would not be able to understand the solution no matter how many times she imitated it (Vygotsky, 1978).

Vygotsky (1986) was one of the first major figures to respond critically to Piaget's ideas. Vygotsky was interested in understanding the socio-cultural context of cognitive development and, in particular, the role of language, which is itself a social construct, in the development of higher cognitive functions (Hodson and Hudson, 1998).

Vygotsky shared the view that, for learning to take place, comprehension is necessary: the natural aim is to make sense of things. However, Vygotsky did not accept the Piagetian theory that learning must wait for development to take place. Vygotsky asserted that children are capable of operating at different levels with learning being possible in advance of development within a Zone of Proximal Development (ZPD) (Carrol, 2005). Pedagogy should be aimed '*not so much at the ripe as at the ripening functions*' (Vygotsky, 1962, p.104).

Vygotsky saw cognitive development as taking place as a result of mutual interaction between the child and those people with whom he has regular social contact (Sutherland, 1992). Those who follow Piaget;s thoughts see the teacher in an enabling role. while Vygotsky advocates a didactic role. However, Vygotsky stressed intellectual development rather than procedural learning . The teacher should extend and challenge the child to go beyond where he would otherwise have been (Sutherland, 1992).

Yang (2000) summarises the key contributions of Vygotsky (1974). He found that social and cultural interaction was the key to success in learning. He rejected the view that intelligence was fixed. On the contrary, he claimed that all children have a potential for development in collaboration with others. His well-known-cognitive theory is characterised by three underlying themes:

(a) The importance of culture;
(b) The role of language;
(c) The idea of Zone of Proximal Development.

Piaget tended to ignore social and cultural influences and build his model on a strict biological basis. He did not lay any emphasis on language, the means by which individuals interact with each other. Vygotsky (1978) addressed some of these issues and brought a useful balance to Piaget's work.

3.9 Conclusions

This chapter has considered the contributions of Ausubel, Bruner and Vygotsky in making sense of how learners develop in their thinking. While Piaget emphasised the biological aspects of cognitive development, Vygotsky noted the importance of culture and support from others in the learning process. Ausubel brought some much needed clarity ot the area of meaningful learning while Bruner emphasised the role of mental experimentation. Together, they build a picture which shows how cognitive skills can develop. It is important to note that cognitive skills do develop with age but the social and educational environment may be very important in enabling such skills to be attained.

Chapter Four

Cognitive Acceleration

4.1 The Cognitive Acceleration

The idea of cognitive acceleration was developed by Shayer and Adey following their early work in looking at Piagetian demand levels in a chemistry syllabus (Shayer and Adey, 1981). Using Piagetian language, Adey (1999) argued that thinking in the sciences is all about encouraging the development of thinking moving from concrete to formal operational. He considered these in terms of the schemata which had to be in operation, these being characteristic of formal operations: control of variables, and exclusion of irrelevant variables; ratio and proportionality; compensation and equilibrium; probability and correlation. Adey (1999) seemed to imply that no student could achieve a GCSE pass (the examination sat in England at age 15-16) in any science subject without using those schemata listed above as part of formal operations.

They developed a series of exercises entitled "Thinking Science" and each activity in these materials concentrates on one of the schema of formal operations although none of them attempts directly to teach strategies for solving problems using those schemata. Adey and Shayer (2002) considered that the current political and social climate was generally friendly to the growth of programmes which develop higher level thinking abilities, in that modern society has very little place for materials based on memorisation without thought and every school student needs to be equipped with flexible thinking skills developed to their maximum capacity.

These materials were designed to being about cognitive acceleration and Adey (1999) defined cognitive acceleration as the process of accelerating students' natural development processes through different stages of thinking ability to move towards the type of abstract, logical and multivariate thinking which Piaget describes as formal operations thinking. This is characterised by the ability to hold a number of variables in mind at once (Mbano 2003).

Adey and Shayer (1994) argue that the aim of Cognitive Acceleration in Science Education (CASE) is to increase the proportion of formal thinkers. Adey and Shayer (2002) also note that Piaget suggested that this type of thinking becomes available to children as a process of natural intellectual development around the age of 14 or 15 years. In contrast to Mbano (2003), Adey and Shayer (1994) suggest that there is a critical period for cognitive acceleration from concrete operations to formal operations which is around 12 years for girls and 14 years for boys.

4.2 The CASE Programme

The teaching strategies used in the CASE intervention programme draw heavily on Piaget's and Vygotsky's theories of cognitive development. In this, they seemed to be thinking more in line with Vygotsky who had shown that it was possible to raise the developmental level slightly, given appropriate support from those who were more developed. They tied their programme tightly to the English curriculum where there are national tests of achievement taken by all pupils at 14 years of age. This offered a useful time for assessment and they linked their materials to ages 11-14. Longer term effects could be measured by looking at GCSE results at around age 16. After much trialling, they developed a series of intellectual exercises, often based on group working, and set in the sciences where pupils could steadily learn the kinds of skills which might accelerate their development. They suggested that the Vygotskan aspect was maybe the "*engine of CASE practice and the Piagetian the gearing*" (Adey and Shayer, 1994). It involved developing just the right match between the cognitive demand of the lesson and the cognitive level of the learners so that were driven on without being discouraged by concepts that they were far too hard.

They suggested six pillars for CASE (Adey and Shayer, 1994, page 896): concrete preparation, cognitive conflict, construction, metacognition, and bridging as shown in the table 4.1 which also illustrates the near equivelence of Vygotsky (1978) and Piaget (1954) and Feuerstein (1990) which is presented in table 4.2.

	Piaget	Vygotsky/Feuerstein
Schemata of Formal Operation	✔	
Concrete Preparation	✔	✔
Cognitive Conflict	✔	✔
Metacognition		✔
Bridging		✔
Construction	✔	✔

Table 4.1 Theory-base of CASE project

It is possible to examine the approaches of Vygotsky and Feuerstein to see areas where they offer similar views and areas where their perspectives are different and this is shown in table 4.2.

Vygotsky Model (ZPD)	Feuerstein Model (MLE)
Vygotsky emphasised the role played by signs, symbols, formulae, texts, graphic organiser, attention, memory etc. that allow the learner to organiser and restructure communication and problem solving.	The child faces two types of learning: The first; the situation of direct learning interaction between learning material and child's mind. The second type of learning; mediated learning
He enphasised that such tools link the individual level of learning with the social interaction around	Mediated learning is described in terms of the quality of interaction between learner and environment which depends on the activity of an adult who interposes him/herself between the learner and environment
'Each school subject has its own specific relation which varies as the child goes from one stage to another" (Vygotsky,1978, p.91).	"Mediated learning experiences are a very important condition for the development of ... the capacity to benefit from exposure to stimuli in a more generalized way than is usually the case". Feuerstein (1990)
The process of concept formation in the student occurs in the constant interaction between the student's spontaneous notions and systematic concepts introduced by teachers.	The role of learning materials is formulated in the context of this overall task of enhancing the students cognitive modifiability through 'mediated learning experiences' producing interaction.
Vygotsky paradigm of teacher training is based on two presupposition. The first is regarding the relationship between instruction and development; The second is the notion of the Zone of Proximal Development (ZPD).	Venger and Gorbov (1993) note that instrumental enrichment programmes are similar to Vygotsky's pre-school and first grade programs.
Vygotsky indiatces that instruction and learning are responsible for the development of higher educational functions.	Mediated learning experiences and instrumental enrichment focus on the formation of the cognitive prerequisites of learning in students
Vygotsky programs aimed at pre-school children have a greater resemblance to the Instrumental Enrichment (IE).	Mediated learning can aid the training of teachers

Table 4.2 Vygotsky and Feuerstein

(1) Schemata Formation

Schemata formation can be thought of as a general way of thinking which can be applied to many different contexts. Inhelder and Piaget (1958) described the schemata of formal operations as control of variables, equilibrium, probability and formal modelling. These were used as a framework within which each activity was developed. The schemata also included: putting things in order according to specific variables; classifying things; and spatial perception.

*(2) Concrete preparatio*n

The development of the schemata is set in real practical contexts. The cognitive acceleration intervention programme was built on specific intellectual problems designed to enable all students to engage with the task. Students need to know the context of the problem they are to face.

(3) Cognitive conflict

Adey and Shayer (2002) discuss the Piagetian idea of equilibration and the Vygotskyan idea of the Zone of Proximal Development (ZPD) (see Vygotsky, 1978). Equilibration is the process by which cognitive processing mechanisms in the mind accommodate to events which can not be readily be assimilated and which create some sort of cognitive conflict. On the other hand the ZPD is the difference between what a child can achieve without any assistance and what he can achieve with the assistance. However both of these ideas show that cognition can be stimulated by the presentation of intellectual challenges of moderate difficulty. Although they do not discuss this, the idea of cognitive conflict is not dissimilar to cognitive dissonance (see Festinger 1957) which has been found to be so useful in attitude development (Johnstone and Reid, 1981)

According to Adey (1999), cognitive conflict occurs when a student encounters a problem which they cannot easily solve on their own. Adey (2002) implies that the teacher presents the pupils with a situation which they cannot tackle with their existing cognitive structure and this is the first stage of the intervention activities. It is described as cognitive conflict which is usually taken to mean cognitive challenge.

(4) Social construction

Adey and Shayer (2002) and Adey (2002) note that the construction of knowledge and understanding is a social process: understanding appears first in the social space that learners share and then becomes internalised by individuals (Vygotsky 1978). Likewise, Piaget also was clear that the environment which composes the cognitive conflict and which stimulates cognitive growth is importantly a social environment. Cognitive acceleration can involve intervention in any subject area and at any age where students are encouraged to describe and explain their ideas, to feel unafraid of getting things wrong, and to engage in constructive dialogue with colleagues while testing out a group understanding.

(5) Metacognition

Adey and Shayer (2002) note Vygotsky's emphasis on language as a mediator of learning but that language also provides the tools for thought. Metacognition takes place when the thinker becomes conscious of his own thinking and develops and practises the techniques necessary for describing different thinking actions. While students are engaging in a problem-solving activity, their consciousness must be devoted to that, and the process of metacognition takes place later. Adey (2002) describes it is as the conscious reflection by a child on his or her own thinking processes, after he or she has worked through a given problem. In this way, the pupils become aware of their own reasoning, and the thinking process becomes explicit. In CASE, students are encouraged to take time to reflect on how they solved a problem and what they found difficult about it.

(6) Bridging

Adey and Shayer (2002, p.6) indicate that '*to be generally useful, new thought processes must be made available across a wide range of contexts. Thus, there is a phase in any cognitive acceleration activity where students are invited to think of other contexts where that schema might be used'*. Adey (1999) sees this as the final pillar: the linking of ways of thinking developed in the particular context of the CASE activity to other context within science, mathematics or other parts of the curriculum and to experiences in real life.

However, Feuerstein *et al*., (1980) suggests that the idea of bridging means taking a strategy or concept from the context where it is learned and using it elsewhere. As teachers learn to see the cognitive content of their normal science lessons in Piagetian terms, they then transfer the class management skills specific to Thinking Science lessons to the rest of their science teaching (Shayer, 1999). It can be argued that the gradual development by teachers of bridging from *thinking science* lessons to the rest of the science curriculum is possibly responsible for more of the long-term and large effects of the CASE intervention than the *thinking science* lessons themselves.

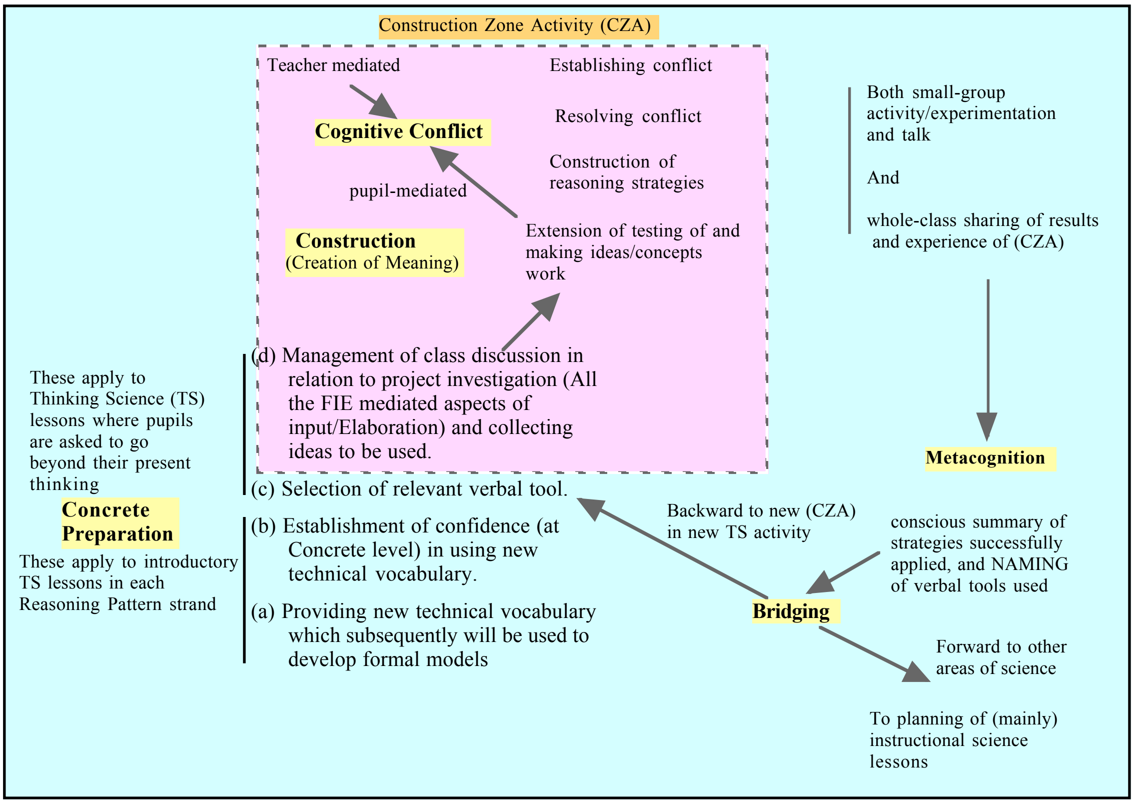


Figure 4.1 Technical Terms used to describe phases in CASE Lessons (Shayer, 1999, page 898)

However, figure 4.1 is a very complicated analysis and of limited value to practising teachers.

In their research, they found that not only did examination performance in GCSEs (English national examination sat around age 16) improve in the sciences but there were measurable improvements in other subjects, including English. Mbano (2003) indicated that, in England, the CASE intervention method has been shown to improve pupil's reasoning skills as well as pupil's performance in science, mathematics and English (Adey and Shayer 1993).

On the other hand, Adey (1999) argued that the teaching methods based on the Piaget-Vygotsky foundation outlined above could be developed in any subject. However, he claims that he chose science because the original detailed description of formal operations provided by Inhelder and Piaget (1958) is characterised by a set of mental schemes like control of variables, ratio and proportionality, compensation, equilibrium, correlation, probability, and use of formal models, these being immediately recognisable by scientists and science teachers as descriptive of important types of relationship between variables. Thus, science presented itself as a most obvious gateway to the development of high-level thinking. However, it is more likely that science was chosen simply because he was himself a chemist!

4.3 Some Outcomes

Mbano (2003) found that the affects of CASE were more pronounced on boys than girls in Malawi while the older boys do less well than younger boys. It was suggested that it was possible that both the girls and older boys focus on surface learning, memorising facts rather than understanding. Meece and Jones (1996) state that girls are more likely to be socialised into rote learning than boys, and, therefore, do less well than boys on new problems that require meaningful learning. Girls are said to memorise algorithms and specific solutions, whilst boys tend to evaluate and use more complex problem-solving solutions. In addition, girls may resort to use of previous knowledge due to their lack of confidence in their reasoning ability.

Mbano (2003) studied the reactions of pupils to the CASE approach. Many pupils (over 70%) stated that in CASE lessons they did more practical work than in other science lessons. It is well known that practical activities are highly popular (Shah, 2004) and this might have generated considerable motivation. Pupils liked working in small groups because they felt it was easier for them to trace their errors when they were carrying out the practical themselves than when it was being demonstrated. Indeed, Mbano (2003) noted that the pupils stated that the work in CASE lessons was done by the pupils and not by the teachers and they saw this as helping them to become independent and self-reliant.

In addition, Mbano (2003) found that the pupils saw the CASE lessons as requiring more thinking and less memory work than non-CASE lessons. CASE lessons were also seen as involving more practical work than a normal science lesson. The pupils saw the benefits of doing CASE as gaining practical experience, gaining design of experiments and related CASE concepts, gaining mathematics and science understanding, and improvement in the ability to answer questions.

4.4 Criticisms of Cognitive Acceleration

Shayer (1999) noted that idea of Piaget which involved provoking and then assisting in the resolution of cognitive conflict and that this was likely to assist students own construction of more powerful strategies. However, Vygotsky (1978) offered the insight that only a small proportion of a child's cognitive development is self-constructed: by far the larger proportion is achieved by internalising a successful performance seen in another person in their social environment and or by working collaboratively with their peers in the construction of more powerful strategies.

McLellan (2006) noted that students with 'adaptive world-views' attending CASE schools would be expected to make greater cognitive gains than similar students at normal schools. In addition, he indicated that, although the effects are not strong, those making the highest cognitive gains actually appeared to decline most in motivational terms and, indeed, it was those making average cognitive gains that appeared to change most adaptively.

However, McLellan (2006) found that the students found it difficult to engage with the challenge of the CASE intervention initially as this requires students to reveal what they know already (in the concrete preparation stage of *thinking science* lessons) or the understanding they have reached (during construction, metacognition, and bridging phases. There is a natural fear at the outset in displaying what might be perceived as ignorance.

In addition, he argued that the motivational world-view can only provide part of the explanation for the differential cognitive gains made over the first 2 years at secondary school. McLellan (2006) drew attention to an important observation: some students benefit more than others when each individual has had the same experience. Indeed, it appears that some students gain almost no benefit while others gain considerably. This needs explanation. Leo and Galloway (1996) have suggested that motivational style might provide the missing explanation. Motivational style, as described by Leo and Galloway, is an individual difference variable and refers to the type of motivation students bring to achievement situations. They also indicate that students will view mistakes as part of the learning process and will not be concerned by other students apparently doing better or understanding more quickly than themselves. McLellan (2006) suggests that students do hold one of a number of different world-views at the start of secondary schooling. Thus it is possible that world-view could help to explain the cognitive acceleration effect. He also stresses that the data do suggest that motivation does play a role in cognitive development.

Looking at the high quality learning experiences which the CASE materials offer, it could simply be argued that giving the students extra activities which are well organised, involve group and practical activity (known to be popular) and relevant to the context and content of the established curriculum are bound to bring about some improvement if the skills they offer are those which enable the learners to understand ideas better. However, it is well known that working memory capacity is a major rate controlling factor in performance in most examinations. It is also known that ability to chunk is a key to reducing demands on working memory (see later discussion). The question then is whether their materials are giving some pupils the skills to chunk better and, therefore, perform better? Teaching chunking skills is very difficult in that chunking is such an individual process. The fact that their materials benefitted about half fits this. It seems possible that their series of exercises is giving the pupils experiences in the kinds of skills which might aid chunking skills. For some of the pupils, they are able to respond to these simply because the approach fits their natural way of chunking. This offers an explanation of what is observed, explains why the process brings benefits in other contexts and subject areas and is consistent with ways by which understanding takes place.

Indeed, there may be an added bonus. The work of Piaget does suggest that the learner is seeking always to make sense of the world around and this is the basis of constructivism regarded as an excellent description of how learning takes place (Kirschner *et al.*, 2006). If the use of CASE materials enables the pupils to make more sense of subsequent learning, this will generate a higher degree of satisfaction which will generate more positive attitudes towards the learning experiences. Positive attitudes tend to link closely to more successful learning as measured by examination performance (Hussein, 2006). The practical nature of the activities plus the group work may also have considerable attitudinal bonuses as well.

Chapter Five

Information Processing

5.1 What is Memory?

It has been argued that cognition has an important history (Malim, 1994). Indeed, Hearnshaw (1987) claims that cognitive psychology is both one of the oldest and also one of the newest parts of psychology. As long ago as 1879, William argued for a less formal approach in order to be more concerned with problems which occurred in daily life rather than with the memorisation of nonsense syllables. Significantly, he drew a distinction between memory process and memory structure and proposed that there were two different kinds of memory.

Baddeley (1990) observed that philosophers have speculated about memory for at least 2,000 years but its scientific investigation only began about 100 years ago. A German scholar, Hermann Ebbinghaus decided to apply the experimental methods that had recently been developed for the study of perception to the more ambitious investigation of "higher mental processes" and more specifically to human memory. He notes that Sir Frances Galton was carrying out important, though largely observational, work on memory at the same as Ebbinghaus was studying his lists of nonsense syllables (Baddeley, 1990, pages 1-2).

However, Ebbinghaus (1913) noted from his observations that:

(i) Ease of remembering is related to meaningfulness;
(ii) Forgetting is very rapid at first, just after learning, and then it slows down;
(iii) People attempt to improve order and sense in order to learn.

Although the work of Ebbinghaus seems utterly unrelated to typical classroom learning, he did establish some important principles. Perhaps, the key fundamental finding is that learners are seeking to make sense of information which reaches them. There is a natural tendency to seek to make sense of things, to look for patterns, for meaningfulness. This has enormous importance for the learning of a subject like physics which, by its very nature, offers opportunity to make sense of the physical world around. When physics learning is reduced to the memorisation of information and procedures, then it loses its intrinsic nature and the whole process runs in contradiction to the natural human tendency to seek to make sense of things. Scientific thinking (which will be analysed later) is a key tool in enabling the learner to interpret and make sense.

5.2 Memory Structures

There have been several attempts to build analogies in order to illustrate what appears to be happening in the human memory. One such analogy relates to flow of information while another uses the way computers are constructed as a model of memory.

Thus, Malim (1994, pages 5-6) suggest information processing as:

(a) Mental processes, seen as a flow of information through various stages, perhaps illustrated on a flow-chart. This includes both the flow of information within a person's mind and also the flow of information between the individual and the environment.

(b) Mental processes, comparing them with the operation of a computer with its three components: data, memory and program.

This information processing approach '*can be seen as an attempt to understand the software of a very complex computer*' (Evans, 1983). Malim (1994) goes further by considering the distinctions between top-down and bottom-up approaches and between serial and parallel processing:

Top-Down or Bottom-Up Processing: top-down cognitive processing starts with the broad context within which processing occurs and only after that considers the detailed characteristics of the stimulus being processed. Bottom-up processing starts with the stimuli and only after they have been processed do other factors come into play.
Serial or Parallel Processing: In serial processing, the assumption is made that each stage of the processing sequence must be completed before the next is begun. On the other hand, parallel processing occurs when more than one stage of processing may occur at the same time (see: Allport *et al*., 1972). For example, he suggested that it might be possible to pay attention to more than one thing at a time, provided that different senses were involved.

Ashcraft (1994, page 44) suggested that the computer, in its own way, does many of the things that humans do, things that cognitive psychologists very much want to understand. Because those things are unseen both when computers and humans do them, he argues that there is good reason for drawing 'the computer analogy' to human cognition. Basically, this analogy says that human information processing may be similar to the sequence of steps and operations in a computer program. Therefore, it is possible that thinking of how a computer accomplishes various tasks will give us insight into the way humans process information.

Seen this way, the computer system has a device that receives information, a central processor where the symbols in the computational formulas are applied to the data, a memory store, and a device that communicates to the outside world by generating output (Ashcraft, 1994, p.46). Of course, computers are all designed by humans and their very design features may well copy the way humans think. Equally, it may simply be that this is the best way by which information can be handled, the circuits of the modern computer being parallel in operation to the protein 'circuits' of the human mind.

Ashcraft (1994, page 210) notes that repetition generated stronger memory, this being derived from Ebbinghaus's early work. This suggests that frequency is a fundamental variable in learning: information that is presented more frequently will be stored more strongly in memory. It is more difficult to see this in computing terms but it seems to reflect that the human brain actually makes connections and that, if used frequently, these links become more easily accessed.

Baddeley (1990) considers that the human memory is a system for storing and retrieving information, information that is, of course, acquired through our senses. Moreover, Neisser (1967) indicates that the memory, in the sense of storage of information for subsequent analysis, probably plays an important role in many perceptual systems. Probably the most peripheral effects to which the term memory has been applied with any frequency are the very short-term visual and auditory stores that were labelled by Neisser (1967, page 13) as iconic and echoic memory.

Although Baddeley(1990, page 4) considers that memory is a unitary, although complicated, system, it is, nonetheless, not one system but many. The systems range in storage duration from a fraction of a second up to a lifetime, and in storage capacity from tiny buffer stores to the long-term memory system that appears to far exceed in capacity and flexibility the largest available computer. He suggests three questions:

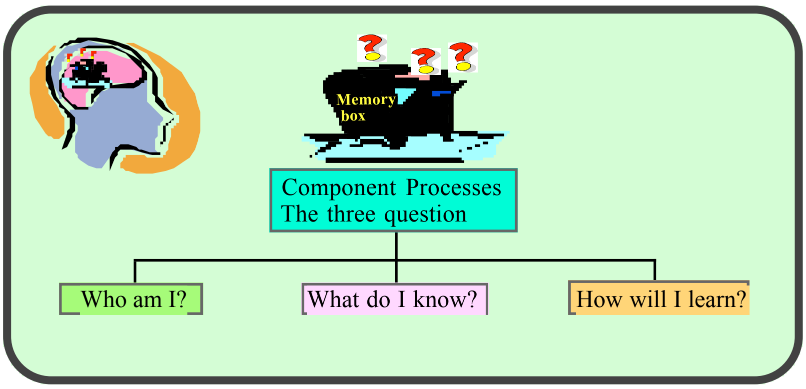


Figure 5.1 Three Questions (derived from Baddeley, 1990, page 6)

However, Baddeley (1990) notes one characteristic of human memory that makes it very different from most computer memories: humans forget.

Based on the cumulation of many decades of research, Baddeley (1995) argues that memory can be divided into three broad components: sensory memory, working memory, and long-term memory. The system includes a visual memory which is sometimes known as iconic memory, and the auditory memory equivalent echoic memory. Baddeley gives a example that, if we had no iconic memory system, we would perceive a film at the cinema as a series of still images interspersed with blank intervals, rather than as a continuously moving scene. Similarly, without echoic memory we would not hear a word, or indeed even a single tone as an entity. Baddeley (1995) describes the working memory (also known as short term memory) as what we use when we have to remember small amount of information for a short period of time, subsequently discarding that information as it ceases to be useful.

Child (1993, page 125-6) notes that some people have better rote memories than others; visual, auditory and kinaesthetic memory (that is, movement memory, which is helpful in touch typing, sport, or any other activity requiring muscle coordination) also varies from one person to another. Furthermore, he refers to three hypothesised processes: encoding, storage and retrieval. Encoding is the process whereby information is thought to be put into the memory; storage relates to the methods assumed to be involved in the retention of information; and retrieval relates to the processes of recovery of stored information from memory. Child (1993) illustrates these ideas (figure 5.2).

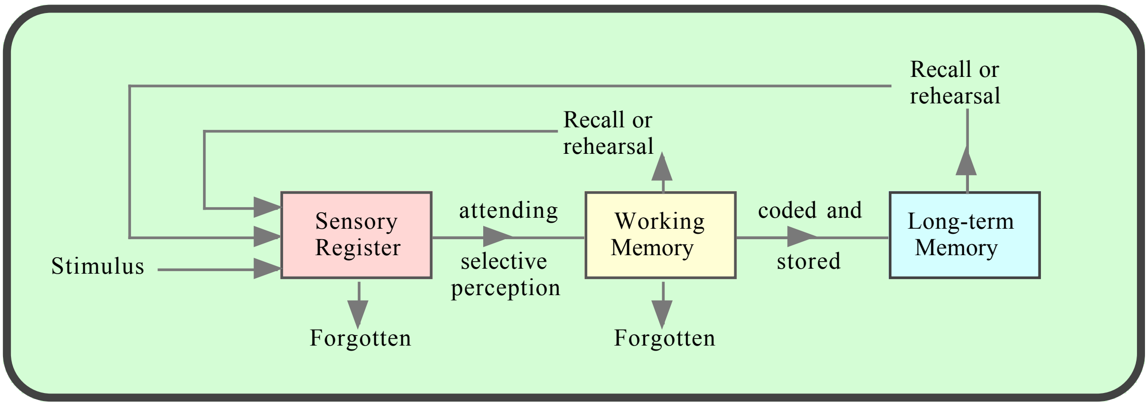


Figure 5.2 Three Memories (derived from Child,1993, p.126)

Lindsay and Norman (1977, page 350-1) indicate that the human memory system works best when it has an organisation for the material that is to be learned, a point noted by Ebbinghaus (1913). To do this it is sometimes helpful to use accidental relationships among the items (such as the common first letter of cone, centre, and colour), since additional relationships make it less difficult to retrieve something from memory. They also comment that, if the need for comprehensive organisation is so great in a library, it is even greater in human memory.

Additionally, Sternberg (1996, page 234) notes that recall from working memory is best for items at the start or at the end of a list. A typical serial-position curve is shown in figure 5.3.

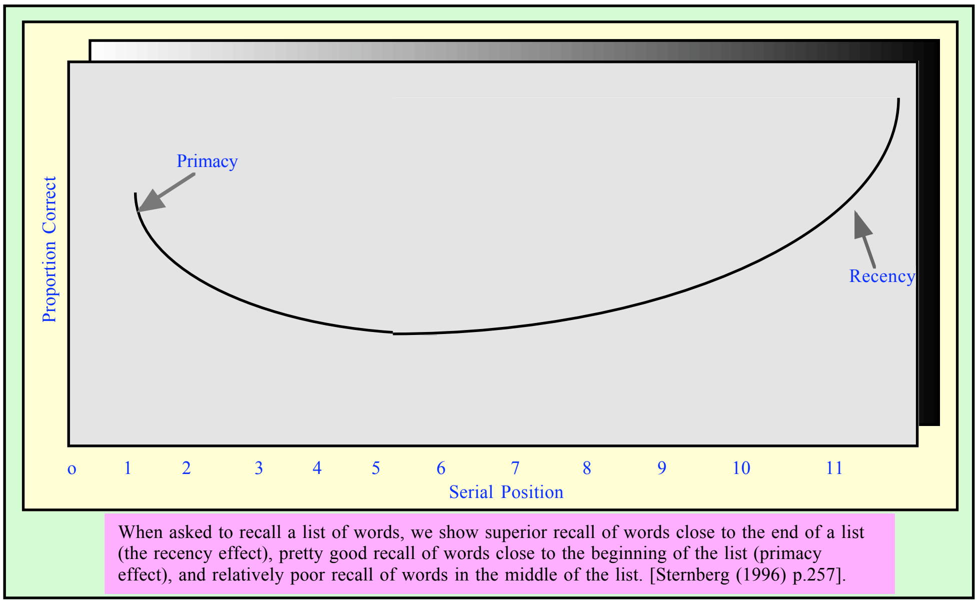


Figure 5.3 Idealised Serial-Position Curve.

The superior recall of words at and near the end of the list is referred to as a recency effect. Superior recall of words at and near the beginning of the list is a primacy effect. As figure 5.3 shows, both the recency effect and the primacy effect seem to influence recall.

The whole issue of remembering and forgetting has generated much research and discussion. (Sternberg 1996, page 259) argues that the key technique people use for keeping information in storage is rehearsal: the repeated recitation of an item. Rehearsal may be overt, in which case it is usually aloud and obvious to anyone watching, or covert, in which case it is silent and hidden. However, the key must lie in understanding how information is stored and, for this, it must be encoded in some way.

Encoding of information in working memory appears to be largely, although not exclusively, acoustic. This can be shown by the susceptibility of information in working memory to acoustic confusability - that is, errors based on sounds of words. Evidence has also been found, however, that shows some visual and some semantic encoding of information in working memory. Information in long-term memory appears to be encoded primarily in a semantic form, so that confusions tend to be in terms of meanings rather than in terms of the sounds of words (see Sternberg, 1996, page 275).

Two of the main theories relating to forgetting are described as decay theory and interference theory. Interference theory suggests that other information causes some kind of interference and makes access difficult. Although it is much harder to assess the effect of decay, while ruling out both interference and rehearsal effects, some evidence of distinctive decay effects has been found. Interference also seems to influence long-term memory, at least during the period of consolidation, which may continue for several years after the initial memorable experience (see Sternberg, 1996, page 275).

Of course, forgetting may simply arise because the transfer of information from working memory to long term memory is flawed in some way. Transfer of information into long-term storage may be facilitated by rehearsal of the information (particularly if the information is elaborated meaningfully), by organisation (e.g., categorisation) of the information by the use of mnemonic devices, and by the use of external memory aids (e.g., writing lists or taking notes). In addition, people tend to remember better when knowledge is acquired through distributed practice across various study sessions, rather than through massed practice, although the distribution of time during any given study session does not seem to affect transfer into long-term memory. Although most adults have developed an awareness of metamemory and frequently use metamemory strategies, young children and retarded learners lack metamemory awareness and skills, and they usually fail to engage in rehearsal or in cognitive monitoring (see Sternberg, 1996, page 275).

Another reason for forgetting may arise from difficulties in retrieval. Environmental context cues during encoding seem to affect later retrieval. Encoding specificity refers to the fact that what is recalled depends largely on what is encoded: how information is encoded at the time of learning will greatly affect how it is later recalled. One of the most effective means of enhancing recall is for the individual to generate meaningful cues for subsequent retrieval (see Sternberg, 1996, page 276). Furthermore, Johnstone *et al.*, (1994) emphasises that, when information from external sources was allowed to interact with information from long-term memory, this can increase understanding. When something is well understood, ideas are strongly interlinked and recall becomes easier. This will be discussed further later.

5.3 Memory Processes

Malim (1994, page 94) notes that the model of memory which underpins much of modern research concentrates upon three memory stages: firstly, there is a learning or input stage which deals with the way in which information enters the memory system and, of course, the factors which are likely to make this process easier or more difficult. Secondly, there is a storage stage which is concerned with how information is organised within the memory system in order to be retained. Thirdly, there is a retrieval stage, concerned with the processes involved in retrieving information from the memory for use.

Bourne *et al*., (1986) observes that human beings have an ability to go beyond information that is immediately available in any situation. We can react to hypotheticals as well as to realities. He also indicates that there are certainly other high-level cognitive processes of which the human mind is capable. The human mind can be described as a system for processing information. Human behaviour can be described as a consequence of information processing Furthermore, he explain how information is processed over time. It is convenient to think of information as passing through several stages, each with its own characteristics. A simplified representation of possible stages of information processing is given in Figure 5.4.

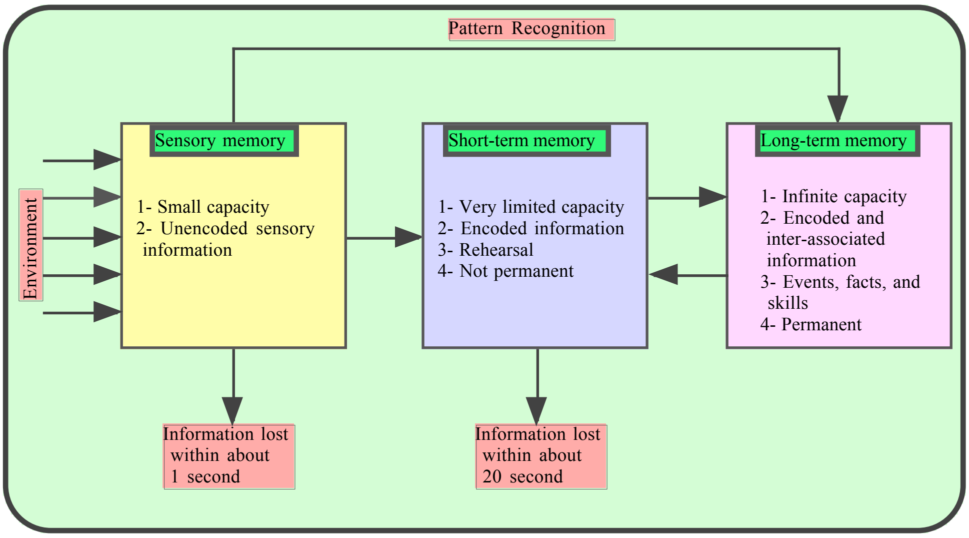


Figure 5.4 A simplified representation of the human information processing system (based on Bourne, 1986, page 12)

From the very beginning, cognitive psychology was concerned with the study of different stages of information processing. These studies led to the important discovery that, before a stimulus can be recognised, it must undergo a complex sequence of perceptual encoding process (Klimesch, 1994; MacKay and Miller, 1996). Figure 5.5 outlines some of the process involved.

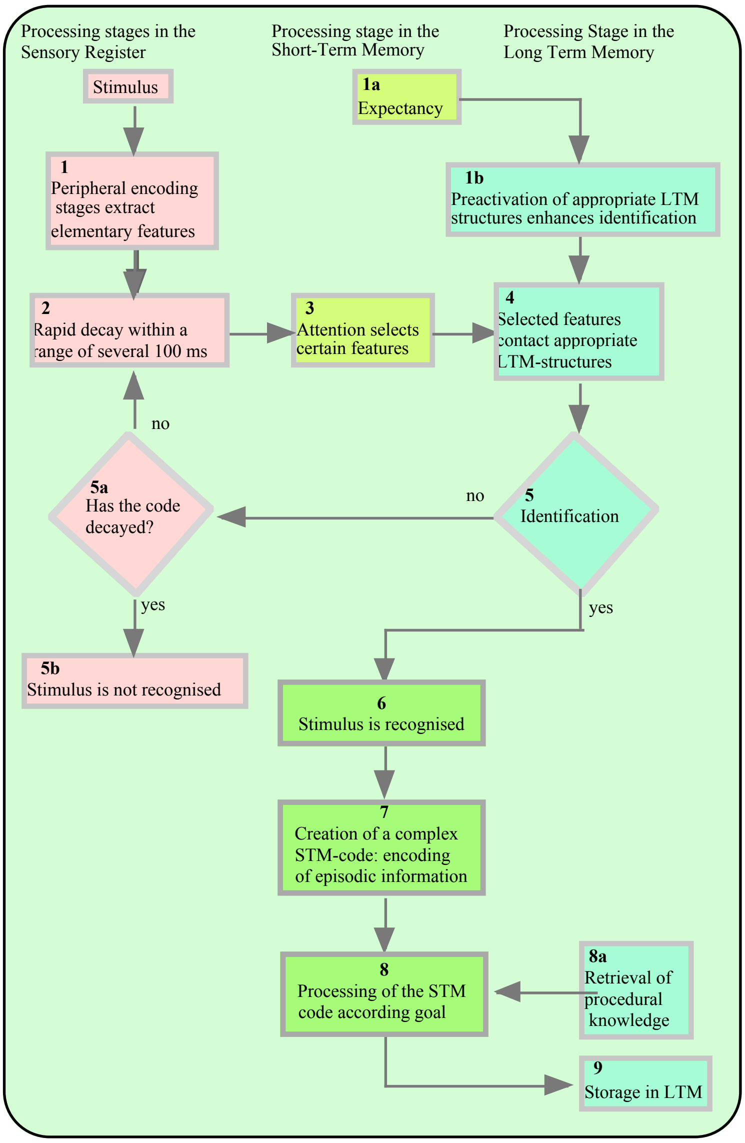


Figure 5.5 Hypothetical sequence of processing stage in human memory.
[Source: Wolfgang Klimesch/University of Salzburg, The Structure of Long-Term Memory: Connectivity Model of Semantic Processing, 1994, p.32.]

In the model shown in figure 5.5, it is assumed that structures stored in long term memory are used to identify sensory information. As a result of this close interaction between long term memory and the sensory register, it is to be assumed that sensory codes and those long term memory structures used in stimulus identification must have a compatible encoding format (Klimesch, 1994, page 35). Klimesch goes on to note that the most important tasks of the sensory register are to coordinate the analysis of sensory information carried out at different rates, and to allow higher cognitive processes to have access to the results of these easy encoding processes. Averbach and Coriell, (1961) suggested that the sensory register is characterised by two important features: an especially high storage capacity and an extremely short storage duration of roughly 200 ms to 300 ms. These features have been examined by Sperling (1960) and Averbach and Coriell (1961).

By the late 1960s, Atkinson and Shiffrin (1968) proposed an alternative metaphor that conceptualised memory in terms of three memory stores: a sensory store, capable of storing relatively limited amounts of information for very brief periods of time; a short-term store, capable of storing information for somewhat longer periods of time but also of relatively limited capacity; and a long-term store, of very large capacity, capable of storing information for very long periods of time, perhaps even indefinitely. Atkinson and Shiffrin distinguished between the structures, which they termed stores, and the information stored in the structures, which they termed memory. Figure 5.6 shows the model suggested by Atkinson and Shiffrin and this model as stood the test of time.

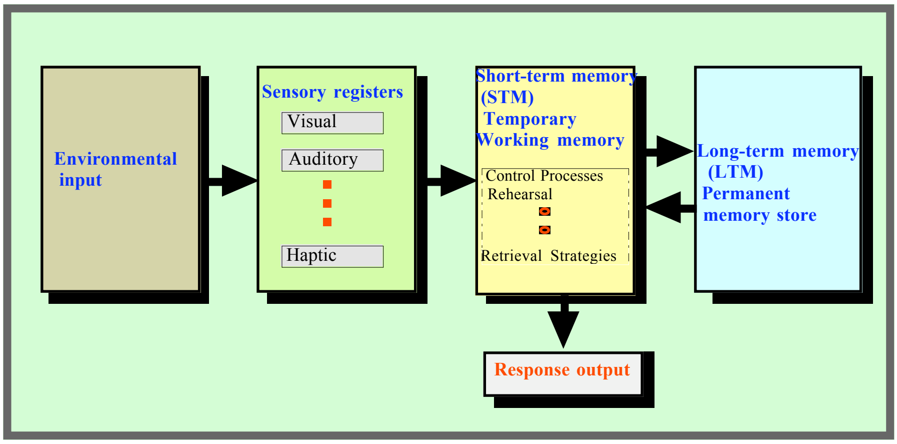


Figure 5.6 The Three Stores Model of Memory
(After Atkinson & Shiffrin, 1968, p. 229)

Later, Johnstone *et al*., (1994) developed the model which will be used in this study. Their perspective was the interpretation of evidence arising from difficulties in learning in the sciences and thus has a strong relationship to teaching and learning. However, it is essentially the same as that arising from the work of cognitive psychologists. It is shown in figure 5.7. The implications arising from this model will be discussed in detail in section 5.7.

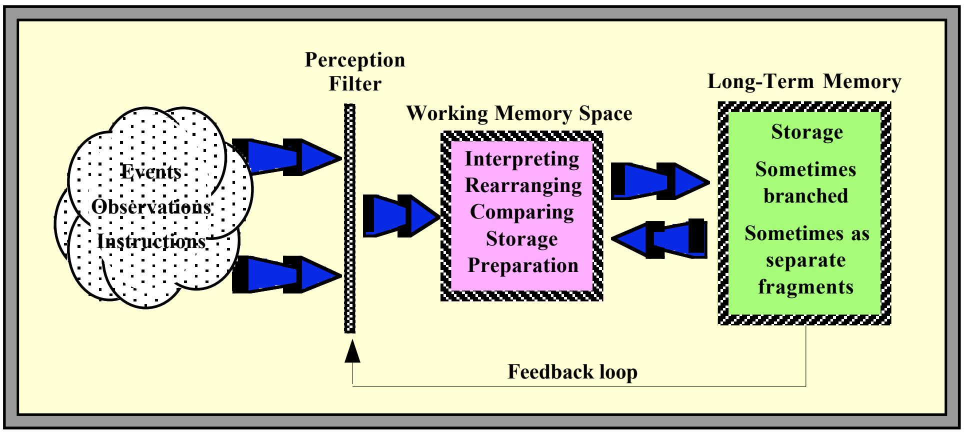


Figure 5.7 A model of learning of information processing.
(Johnstone, et al., 1994, p.78)

Johnstone *et al.,* (1994) clarify a number of issues which had been debated for some time. Working memory is also known as short term memory. This is the place where information is held temporarily but it is also the place where thinking, understanding and problem solving take place. When the space is used simply to hold information, it can be seen as a short term memory. However, the phrase 'working memory' describes its overall function better. In the Johnstone model, the role of the long term memory as a controller of the perception filter is also made clear. What a person knows (including attitudes, feelings, biases etc) controls the selection of information to be admitted to the working memory. This is totally consistent with the evidence discussed by Ausubel (1968).

The nature of the long term memory is also made more clear by the Johnstone model. Here, information can be stored in a highly interlinked way or it can be stored as separate fragments. When there is much interlinking, it is more likely that the person understands the concepts and ideas and, as a result, will be able to use, apply and recall the information more easily. Kempa and Nicholls (1983) showed that student performance was clearly related to the degree of concept interlinking existing in the mind of the student. They were looking at algorithmic problem solving. In a later study, Reid and Yang (2002a,b) suggested that the links between what they called 'nodes' of knowledge held in long term memory were critical in much more open-ended problem solving. This has been supported in some detail by very recent work by Al-Qasmi (2006)

5.4 Memory Functions and Capacities

In his classic work, Miller (1956) demonstrated that the capacity of the working memory is limited to 7 ± 2 items. He used the term "short term memory'. He described the 'items' as 'chunks'. The nature of a chunk of information is determined by the individual person. One piece of information is what the person sees as one. With experience, a person can link pieces of information together so that they are seen as one chunk and, thus, they take only one space in the working memory. Thus, while it is possible for the average person to recall only about seven unrelated digits, it is not too hard to recall a telephone number (e.g. 071 234 5498). These ten digits would normally be beyond most people's span but because they are grouped, the number is little more difficult to recall than three items would be.

Baddeley (1990) refers to an example from Hamilton (1859). If a handful of marbles is thrown on the floor, it is difficult to view at once more than six or seven at most without confusion. However, if they are grouped into twos, or threes (or even more), it is possible take in about seven groups because the mind considers these groups as only units. Slak (1970) saw this technique (which Miller (1956) described as chunking) as a way to increase digit span and to enhance long-term learning of numbers.

The key thing to note is that Miller's insights demonstrated that the memory span of the working memory should be seen as 7 ± 2 chunks, the chunk of information being seen as what the person saw as one unit, a point stressed by Baddeley (1990). A chunk is an integrated piece of information. Skills in chunking (grouping items together into a meaningful whole so that they are seen as one item) grow with learning and with experience. They are difficult to teach as they tend to be idiosyncratic. Chunking also plays an important role in long-term memory in that groups of items can be stored as one chunk in long term memory (see Otis, 2001).

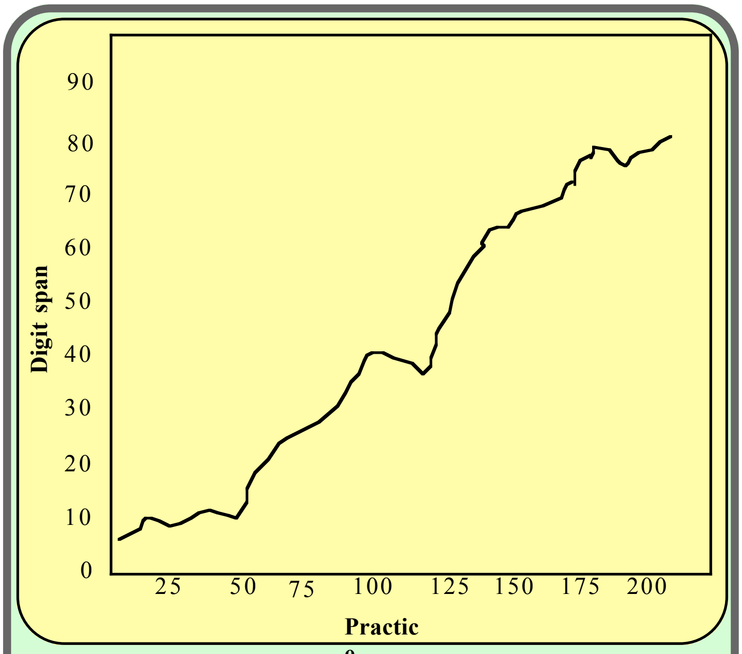
The capacity of working memory grows with age, there being a growth of approximately one unit for every two years to the age of 16 when the final and fixed capacity [7±2] of working memory is reached (Baddeley, 1990). However, there is also the issue of speed of processing. How fast can the working memory be used? How fast can it be cleared from one task and then be available for the next task? Nicolson (1981, page 77) made the interesting suggestion that this might be due to a tendency for older children to rehearse faster. He studied the speed at which children of different ages could articulate, and plotted their memory span as a function of this, finding a very clear relationship.

Baddeley *et al.,* (1975) noted that we do not recall more than about seven or so digits which is roughly the amount a person can say out loud within about two seconds. However, if we speak the sequences aloud, we will probably do somewhat better than if we simply read them to ourselves. The reason for this is that articulating and hearing the sounds of the numbers registers them in a brief auditory memory store. Another way of improving our performance would be to group the digits rhythmically. This technique appears to help reduce the tendency to recall them in the wrong order. Baddeley (1994) emphasis as that recalling in reverse order is much more difficult than normal auditory recall.

Baddeley (2003) notes that it is frequently asserted that the comprehension of both written and spoken language depends on some form of working memory (e.g. Atkinson and Shiffrin, 1968; Kintsch and Van Dijk, 1978). He goes on to observe that comprehension results resemble those obtained in studies of working memory and learning, suggesting a clear deterioration in performance when the subject is holding a six digit memory load, but little or no deterioration when the load is reduced to three digits. This type of work was explored in much more detail by Johnstone (1997) and will be discussed later.

However, Bourne *et al*., (1986) stress that long-term memory and working memory, despite their demonstrated independence, can interact in fairly integrated ways. Chase and

Ericsson and Chase (1982) present an analysis of a single subject illustrating how the long term memory can bring about massive enhancement in the apparent capacity of the working memory. This allowed dramatically increased enhancement of digit span capabilities and these showed no sign of reaching any limit (see figure 5.8). This does not necessarily imply an increase in working memory capacity but it does demonstrate that there are things which can be done to enable the capacity to be used with markedly increased efficiency.



Growth in digit span for the subject after 200 days of practice, this learning curve showing no signs of levelling off.
(Redrawn from Figure 1. p. 608, in Ericsson and Chase, Exceptional Memory, 1982)

Figure 5.8 Growth in Digit Span

Despite such remarkable results, the observation is that the capacity of working memory is fixed and very limited. Capacity limitation places severe constraints on people's ability to process information and to solve problems. The experiment described by Chase and Ericsson and Chase (1982) appears to defy this limitation. However, it is first important to note that the skill did not develop overnight. Rather, it was the consequence of long and tedious practice. According to Chase and Ericsson, the skill depended very heavily on an ability to make use of information already permanently present in his long-term memory and to retrieve and utilise that information in an exceptionally rapid and efficient way. The subject rapidly encoded these digits into chunks of three or four numbers, corresponding to what he knew about running times. He developed a skill of accessing his extensive knowledge of running time numbers almost instantaneously and using that knowledge to recode a long string of digits into something more manageable. They emphasise that the performance described here really does not disprove the fundamental limitation on human

working memory: switching to another memory task shows the limitation.
Towase and Hutton (1998) state that working memory span tasks are reported to provide better predictions of reading skill than do word span tasks (see Daneman & Carpenter, 1980). In support of that Case *et al.,* (1982, page 196) found a linear relationship between memory capacity and processing speed, so that older children who counted more quickly obtained higher spans. Hitch and Towse (1995) suggested that children do not share resources between processing and storage and that counting span does not measure the amount of working memory resources available for trading between these functions.

5.5 Episodic and Semantic Memory

It is important that semantic connections (that is to say, understanding of meaning) are involved in the process of coding for long-term memory but that is not the only way in which it is organised. There is great diversity, not only in what is stored - all kinds of knowledge and beliefs, objects and events, people and places, plans and skills - but also *how* it is stored.

Tulving (1972) suggested in the model of memory proposed a distinction between episodic and semantic memory. However, Johnson and Hasher (1987) contend that episodic and semantic memory have not been shown empirically to be separate systems which can be isolated from one another. Semantic memory is where your knowledge of language and other conceptual information is stored. It is the permanent repository of information you use to comprehend and produce language, to reason, to solve problems, and to make decisions. Whereas episodic memory is a personal, autobiographical store, semantic memory is a generic storehouse of knowledge (Ashcraft, 1994, page 354). Baddeley (1990, page 354) sees semantic memory as the system by which we store knowledge of the world. Attempts to study it have been strongly influenced by theories from linguistics and computer science while some of its conceptual problems, such as the nature of meaning have preoccupied philosophers for centuries.

Baddeley (1995, page 7) gives an example of an episodic memory which recalling the experience of having breakfast this morning, or of meeting someone a year ago on holiday. On the other hand, semantic memory represents the accumulation of information from many, many episodes or layers of experience, implying that rather than being a separate system, semantic memory is made up from multiple episodic memories. However, a distinction that appears to have much stronger experimental support is that between procedural and declarative learning. Procedural learning comprises the acquisition of skills, such as learning to type. Here, the demonstration of learning is reflected in the more efficient performance of the skill. In this respect it is different from declarative learning which involves learning things: procedural learning is knowing how; declarative learning is knowing that (Baddeley, 1995, page 8).

Episodic Memory	Semantic Memory
is memory for fairly transitory events in our experience.	can be described as memory for more permanent items of
is based upon sensations.	based upon understanding
is time related.	is related to concepts
is very subject to forgetting	is less so individual than episodic memory.

Table 5.1 Episodic and Semantic Memory

5.6 Three Memory Components

The models of memory involve three memory components: sensory memory (sometimes called perception filter), working memory (formerly known as short-term memory), and the long-term memory (e.g. Ashcraft, 1994). In the computer analogy, these three correspond, respectively, to the receiving or input buffer device, the central processor, and the library of programs and data that are stored and available for use (Ashcraft, 1994, page 50).

Each is now discussed briefly in turn.

Sensory Memory

Information is received by humans at an enormous rate, mainly as visual or sound signals. The sensory memory encodes these external stimuli and enables them to be passed to the working memory. The key function of the sensory memory is to act as a perception filter, selecting out those signals to pass to working memory and rejecting the others. There is evidence to the effect that the impression left by a sensory experience may persist in all its complexity, either at the receptor level or in the brain, for a brief period of time. This persistence is called sensory memory. Sensory memory will record for a very short period of time nearly an exact replica of the event that occurred in the environment.

The selection process is controlled by what is held in long-term memory. Some learners are extremely good at selecting what is important for the task in hand while others are much less efficient. This first group are often described as field independent (Witkin, 1974) and have the enormous advantage that only what is essential is passed to the working memory, thus reducing the possibility of overloading of that memory.
The importance of the selection process is considerable. As the selection is based in what is held in long-term memory, previous knowledge and the way that knowledge was

obtained has a powerful influence on new learning. In addition, emotions, fears, doubts, attitudes, prejudices and beliefs may also affect the selection process. For example, a bad experience in an area of learning can seriously hinder future learning in that area while the lack of reward in many educational systems for anything other than the correct recall of knowledge and procedures may block future learning like the development of critical thinking or scientific thinking. These may be perceived as offering no advantage in passing examinations.

Working Memory

If the learner is paying attention, selected signals received by the sensory memory are passed rapidly to the working memory where the information is held for further mental processing (Ashcraft, 1994, page 51). The working memory not only receives information from the external world, but it can also receive information from the long-term memory. Part of its function is to encode information from the external world and link it on to information already held in long-term memory (Ashcraft, 1994, page 17). The functional duration of short-term memory information is about 15-20 seconds (longer if it is rehearsed). Malim (1994) thinks in terms of not longer than 30 seconds.

The key feature of the working memory is its limited capacity (7 ± 2 chunks of information). However, its role is not only to hold information before passing it for storage but also to think, understand and problem solve. Thus, if there is too much information, it becomes very difficult to understand or problem solve. This is a common problem in highly conceptual areas of learning (like physics) where many ideas have to be held at the same time. Frequently, there is too much to hold and understanding cannot take place, leading to rote memorisation and a high level of intellectual dissatisfaction (Ashcraft, 1994).

Baddeley (1990) notes that the working memory has a limited storage capacity but relatively rapid input and retrieval. Long-term memory, on the other hand, has an enormous capacity but tends to be slower to register information and retrieve it. From his research, Baddeley (1994) shows that, while the working memory is involved in reasoning, comprehending and learning, this involvement is by no means total. There seems to be some overlapping components involving working memory and other components of memory. Indeed, he has found evidence for various loops in the working memory with specialised functions. Evidence suggests that we can hold active in short-term memory only some small number of items of information at any given time. To keep information alive in short-term memory, we must engage in further processing (Bourne *et al.*, 1986). The rehearsal may involve the loops described by Baddeley.

Overall, working memory serves as a ‘bottleneck’ in the information processing system. Only so much can get through or can be worked on at any particular point in time. This has great implications for all learning as many studies have shown (e.g. Christou, 2001; Al-Enezi, 2004; Chen, 2004; Danili and Reid, 2004; Hindal, 2007; Chu, 2007).

The working memory seems to have another function. Baddeley describes this in terms of the central executive function (Baddeley, 2000). The working memory controls the way information is handled. It seems to be able to link to long-term memory to gain access to previously held information. It seems to select and to be able to carry out processes on information, using procedures stored in long-term memory (see: Klimesch, 1994; Baddeley, 1981; Daneman and Carpenter, 1980; Atkinson and Shiffrin, 1968). Thus, Sternberg (1996) explains that, according to the Atkinson-Shiffrin model, the working memory holds a few items but also exerts some control processes that regulate the flow of information to and from the long term store, where we may hold information for longer periods of time.

Long -Term Memory

The long-term memory is the ultimate destination for information we want to retain, the memory system responsible for storing information on a relatively permanent basis (Ashcraft, 1994). He also argues that more current theories suggest that no information is truly lost from long-term memory, except for cases of physical damage to the brain itself. Instead, it is almost as if information gets lost in long-term memory: it is still there but it cannot be located or retrieved.

Not only can some learning not be retrieved, it is also possible that misunderstandings can arise. An example illustrates this. McCloskey and Khol (1983) have investigated people's conceptions of the physical world, in particular, their understanding of the principles of motion. They have provided a very convincing example of the misconceptions or faulty mental models that people often have. For instance, in one of his studies (McCloskey *et al*., 1980), 51% of the subjects wrongly believed that a marble would follow a curved path after leaving a curved tube lying on a table. Likewise, in a model of tracking the path of a ball dropped from an airplane, only 40% gave the correct answer, the most common incorrect answer (36% of the subjects) being that the ball would fall straight down. Figure 5.9 shows both the correct and incorrect answers that people gave to these problems, along with the percentage of people who gave the answer. As McCloskey notes, despite having many opportunities in our daily experience to observe the behaviour of objects in motion, and to gain an understanding of the principles of motion, we often adopt a faulty mental model.

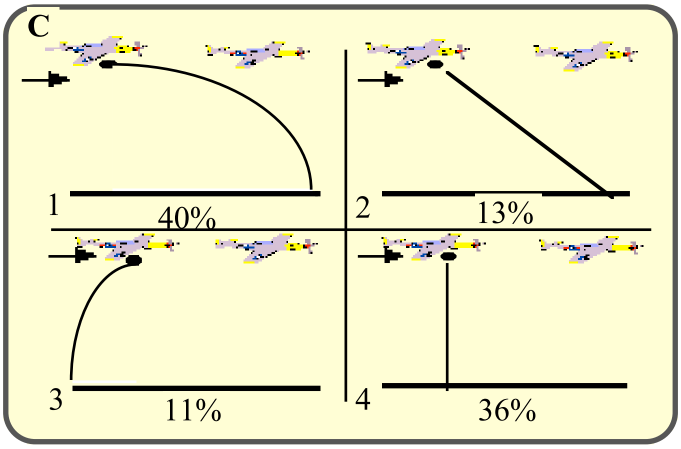


Figure 5.9 Moving projectile: from McCloskey and Khol , 1983

In the tube problem, one subject said: "*the momentum from the curve [of the tube] gives it [the ball]the arc....The force that the ball picks up from the curve eventually dissipates and it will follow a normal straight line*" (McCloskey and Khol, 1983, p.309).

The correct model, of course, is that a moving object will continue moving in a straight line unless acted upon by some other force. Thus, when the ball leaves the tube, the ball will move in a straight line. There is no such things as a 'curved force'. The same pattern of movement can be seen if an object is dropped from an aeroplane. While the vertical movement accelerates, the horizontal movement continues on (with slight changes due to air resistance or wind movement, depending on the shape of the object). McCloskey and Khol (1983, pages 564-5) note that the '*naive belief in impetus*' has been accepted for longer than Newton's Laws in the history of humans. Nonetheless, such a belief does not fit the evidence and is an alternative conception.

Wrong understandings, alternative conceptions or misconceptions can all occur as the learner seeks to make sense of the world around. They can arise as observations are misinterpreted. They can also arise as new information and experience are incorporated wrongly with knowledge and understandings previously held in long term memory. Lindsay and Norman (1977) stress that the major task in the learning of new material is to integrate it properly within the structure of information already present within long-term memory. Material that is to be retained must be structured in a way that allows its retrieval later on. Deep or meaningful learning occurs when new information is stored in long-term memory by connecting it to existing information to form a branched network. The stored information will then be more readily available for use at a later time (Johnstone *et al*., 1999).

When the word 'memory' is used, it is usually long-term memory which is in mind. Thus, Sternberg (1996) note that when we talk about memory, we are usually talking about long-term memory: where we keep memories that stay with us over long periods of time, perhaps indefinitely. It is not known how to test the limits of long-term memory and thereby find out its capacity. Thus, most assume that the capacity of long-term memory is infinite, at least in practical terms (Bahrick, 1984a, 1984b; Bahrick and Hall, 1991; Hintzman, 1978).

5.7 Constructing a Model of Learning

Johnstone directed a long series of studies which looked at the difficulties in learning in high concept areas of the curriculum like chemistry. Johnstone brought many of the findings together in his information processing model (figure 5.10).

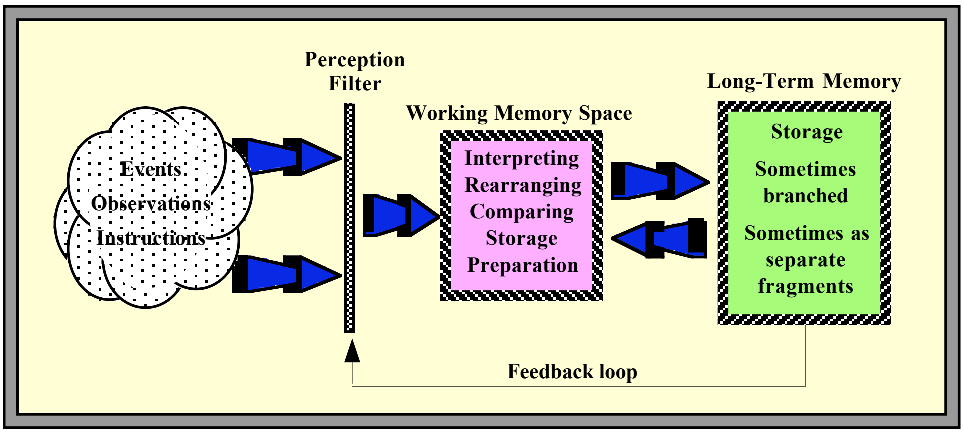


Figure 5.10 An Information Processing Model (source: Johnstone, 1997)

In doing this, he drew together findings from much research over a period of many decades. The key features of his model include the selection facility of the perception filter and the way this was controlled by long term memory; the 'bottleneck' of the limited capacity of the working memory; the variable ways by which information can be stored in long term memory, thus accounting for the presence of rote memorisation, misconceptions and the development of understanding; the place of experience and attitude development as an integral part of the learning process.

In simple terms, speaking of the working memory, Johnstone (1997) stated that. '*if there is too much to hold, there is not enough space for processing; if a lot of processing is required, we cannot store much*'. The model also explained the idiosyncratic way selection takes place in the mind of each students, by which the things we are teaching are deemed to be important or unimportant, understandable or baffling, interesting or boring. All of this is controlled by what is already held in long-term store which varies from person to person.

Johnstone (1997) noted that, '*Learning is not the transfer of material from the head of the teacher to the head of the learner intact. Learning is the reconstruction of material, provided by the teacher, in the mind of the learner*.' This absorbed the arguments from constructivism but did not fall into the trap described by Kirshner *et al.,* (2006) when they stated that, '*Any instructional theory which ignores the limits of working memory ... is unlikely to be effective.*' (page 77) and '*The constructivist description of learning is accurate but the instructional consequences do not necessarily follow*' (page 78). Their insights are highly perceptive.

5.8 The Idea of Pre-Learning

There are several very simply predictions which the model offers. It is known that, if the working memory is overloaded, then meaningful learning more or less ceases (Johnstone, 1997). Overload can be reduced if the perception filter selects more efficiently. This is controlled by what is already known and stored in long term memory. This led to the idea of pre-learning and a major series of experiments on this are described by Sirhan *et al*., (1999)

Students in a large (160-222 each year) university first year chemistry class were given pre-learning experiences in the first two years, these being discontinued in the next three and then, finally, pre-learning was re-introduced in a paper form known as 'chemorganisers' (these are available on line) in the final year. The original pre-lectures involved short activities based on previous knowledge and this was undertaken *before* each lecture course. When these were no longer used, the extra time was given over to the lectures. In the sixth year, students were offered some paper-based materials (covering abut 60 topics) which aimed ot give them the background knowledge which would be needed so that the students could make sense of the lecture courses to follow.

The aim of pre-learning was to remind the students (or perhaps teach them for the first time) about the ideas which underpinned any understanding of the material to be presented in the lecture course. This new material then was more easily understood as the working memory was less likely to overload. This was hypothesised to arise simply because the information in the long-term memory would enable the perception filter to work more efficiently. The students could see more easily what was important and how it fitted together so that unnecessary information was not selected into the working memory. There was also another predicted advantage. With pre-learning, there was now a better chance that new material would be linked correctly and meaningfully on to previous knowledge held in long term memory.

What was remarkable was that the experiences known as pre-learning had the greatest benefit for those in the class who were *least well qualified* in chemistry (The Lower Group). Thus, the less well qualified group (lower group) did statistically as well as the better qualified group (upper group). This shows the power of pre-learning as can be seen in table 5.2.

First Year General Chemistry Class					
Year	**Pre-learning**	**Upper Group Average**	**Lower Group Average**	**Difference**	**Significance**
1993-94	**pre-lectures**	**50.9**	**48.8**	**2.1**	**not sig**
1994-95	**pre-lectures**	**49.2**	**49.0**	**0.2**	**not sig**
1995-96	**no pre-lectures**	**46.9**	**38.7**	**8.2**	**sig**
1996-97	**no pre-lectures**	**48.2**	**42.0**	**6.2**	**sig**
1997-98	**no pre-lectures**	**46.7**	**41.3**	**5.4**	**sig**
1998-99	**Chemorganisers**	**49.8**	**47.7**	**2.1**	**not sig**

Table 5.2 The Effects of Pre-learning

Pre-learning has a very large effect in making laboratory learning much more effective. In one experiment in physics (Johnstone *et al*., 1998), students undertook four experiments, two with pre-learning experiences and two without. The sample was a large first year university class. Tests for understanding were applied afterwards and, on average, the performance in these rose by 11% as a result of the pre-laboratory experiences. Another study was conducted in chemistry, with even larger numbers ($N > 500$) and, yet again, the power of pre-learning, as predicted, to improve understanding was very marked (Johnstone *et al*., 1994). There was an added bonus to the second experiment in that it was shown very clearly that open-ended experimental laboratories could be conducted and that pre-learning had a very large effect in enabling these to work well.

Such pre-learning is evident in many school classrooms where, by skilful use of questions and recapitulation, the class is reminded of previous learning which, in turn is then able to inform the perception filter. Working memory overload is less likely and subsequent understanding is enhanced. This offers a simple explanation of a practice which good teachers have used for generations.

5.9 Reducing Working Memory Overload Directly

Reid (2008) shows that it is not too difficult to reduce the overload on working memory of the students by changing the way complex material is taught. In addition, Reid (2008) emphasises that the information processing model predicts that student learning and understanding will be improved by reducing the demand on the working memory during the learning process. However, it might be thought that that working memory load cannot be reduced without changing the content to be taught or without increasing the time allowed for teaching and learning. Reid shows that neither is necessary. Indeed, he goes on to show that reducing the working memory demand does not mean changing the content or avoiding difficult themes but simply by changing the way the content is taught.

Danili and Reid (2004a) re-designed a large section of chemistry teaching at school level, to reduce the overload on working memory. They found a marked improvement in performance and showed that this was independent of any teacher effects. This was achieved by re-organising the order of presentation, sequencing the ideas carefully, by reminder and illustration, by a stepwise approach, and the careful use of diagrams.

Working on a much larger scale, Hussein (2006) conducted a careful experiment in the Emirates in which four large areas of the curriculum were completely re-cast in order to reduce working memory overload problems. He also was seeking to develop other features in the new teaching materials he produced but these will not be considered further here. He found a remarkable increase in performance in the school national examinations and suggested that this was directly related to the working memory load reduction. His study was conducted ‘at a distance’ and involved no contact with any of the teachers involved and no re-training of them.

A similar result was found in Taiwan (Chu, 2007) in the area of learning genetics with younger school pupils. Genetics is well known as an area of difficulty in biology because of working memory overload. Indeed, Chu found a very high correlation between performance in genetics examinations and the measured working memory capacity of the students involved. In her work, Chu (2007) observed the same marked improvement in performance and also considerable changes in attitudes with her re-written teaching approaches.

Reid (2008) summarises the findings in figure 5.11

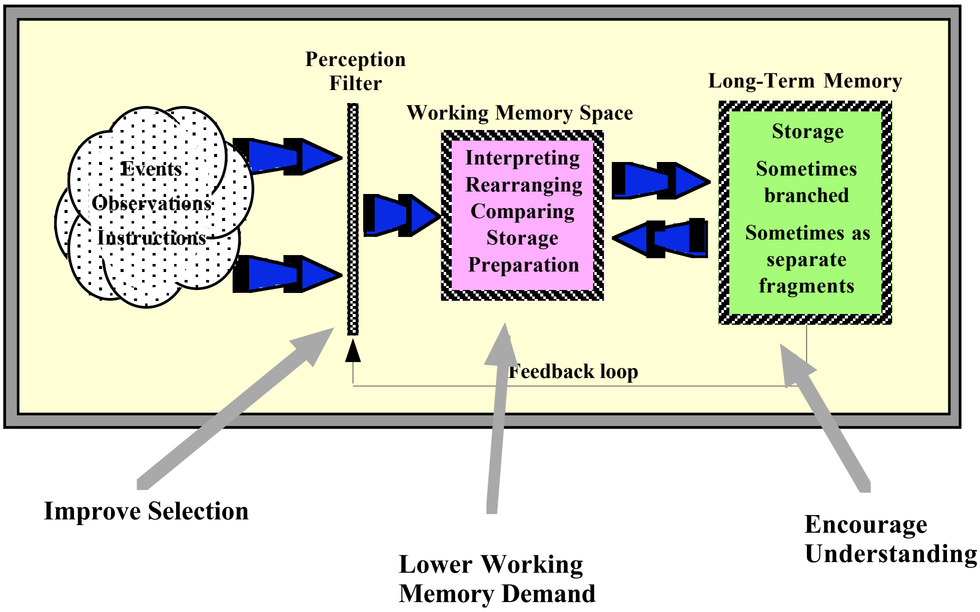


Figure 5.11 Three parts of Information Processing

He offers a summary of the findings from numerous experiments:

> *'Understanding can be enhanced by:*
>
> - *Selection can be improved by pre-learning.*
> - *Lowering working memory demand can be achieved by changes in presentation.*
> - *Understanding can be increased by deliberately linking new material to older.'*

Thus, it seems that re-organising teaching to reduce the overload on working memory directly is possible and there are examples of experiments where this has been tested and *very marked* improved performance in tests of understanding have been observed. This reduction of working memory overload is not a matter of trivialising what is to be taught. It does involve re-thinking the way complex material is presented.

Thus,

> *'The key thing to note is that working memory causes a problem when too much has to be thought about at the same time. By careful sequencing of ideas, by reminder and illustration, by a stepwise approach, the working memory is not faced with too much at the same time, it is predicted that learning will increase.'*
>
> (Reid, 2008)

5.10 Conclusions

Information processing, as it applies in the sciences, developed as a result of patterns which were observed relating to areas of student difficulty. This led to the model which was used extensively by Johnstone (1997) to interpret and rationalise many findings relating to the learning of conceptual material. The power of the model lies in its ability to predict. Specifically, the development of pre-learning in formal teaching as well as laboratory learning has been shown to be very effective. The model also predicted that, if teaching was brought into line with the limitations caused by working memory capacity, then learning, defined in term of understanding, would be enhanced greatly. Various studies have confirmed this.

If the model of information processing correctly represents what is happening in all learning, then it must be relevant to the acquisition of those thinking skills called scientific thinking. Specifically, the process of hypothesis formation will almost certainly require not only considerable experience in a science, but, more importantly, will make demands of limited working memory capacity. This almost certainly explains why Piaget (1964) observed that the skill of hypothesis formation did not start to develop until the formal operations stage of cognitive development (from age 12 onwards). Thus, it is highly unlikely that scientific thinking in any recognisable form can occur before age 12 and, indeed, as formal operational skills develop over the period form age 12-16, it is likely that genuine understanding of the place of the hypothesis will not be seen until the students are nearing 16.

Chapter Six

Difficulties in Learning Physics

"The relation between traditional physics textbook problem solving and conceptual understanding was investigated. The number of problems a student solved, as estimated by students themselves, ranged from 300 to 2900 with an average of about 1500. The students did not have much difficulty in using physics formulas and mathematics. However, we found that they still had many of the well-known conceptual difficulties with basic mechanics, and there was little correlation between the number of problems solved and conceptual understanding. Problem solving has a limited effect on conceptual understanding."

Kim and Jae (2002)

6.1 Introduction

Watts and Pope (1989) argue that science teaching is not just the transmission of knowledge but also involves the organisation of the situations in the classroom and design of tasks in ways which promote scientific thinking. They see the curriculum in terms of learning tasks, materials and resources from which students construct their knowledge and not a catalogue of things to be learned. Young and Schofield (1976) go further when they advocate that the problems in science education are not just problems of curriculum reform and more 'relevant' courses, but problems which have their origins and their resolution in a particular kind of society and its transformation.

These illustrate a dilemma for science education in general and physics education in particular. Is the task of those involved in physics education to pass on a body of knowledge or is the task that of seeking to develop understandings of the way physics interprets the world around? Physics teaching might aim at understanding but this might still not enable the learner to apply their knowledge in ways which are productive. Furthermore, there is the difficult issue about the way physics, as a science, develops its understandings. This belongs to the area of scientific thinking. Where does this fit into the teaching and learning process? There is yet another issue: is physics education a part of education *for all* in the making of informed citizens or is to be kept as the part of the education of a minority who will need it for future careers or training?

Reid (1999) considered the reasons which might underpin the curriculum in physics (and the other two sciences) at school level. In Scotland, all study topics in physics up to age 14. For every 100 pupils in Scotland, roughly 40 are taking physics at age 15+ and roughly 20 at ages 16-17. Physics, compared to most countries, is popular in Scotland.

However, the curriculum at each stage cannot be decided by the needs of those entering the next stage, simply because that would mean that the curriculum would be determined by minorities and might well fail to meet the needs of majorities. Thus, there is no support for the idea that secondary school pupils should take physics in order to prepare them to be physicists (or even scientists). Kesner *et al*., (1997) note that, in recent years, science educators and curriculum developers have realised that science is taught not only in order to prepare for university studies and careers in science, but also to become citizens in a society which is highly dependent upon scientific thinking.

Research suggests that physics and chemistry are considered among the most challenging school subjects (Soy, 1967; Stronk, 1974; Farenga and Joyce, 1999), a view shared by elementary school teachers who believe that physical science is a most difficult subject (Behnke, 1959; Ramsay and Howe, 1969; Schimer, 1968). Indeed, Stronk (1974) noted that even among high achieving students, physics is perceived to be the most difficult subject, followed closely by chemistry.

The research on difficulties has tended to focus strongly on understanding the concepts of physics with little attention to applications and scientific thinking. For example, Gunstone and Wight (1981), in their investigation of the learning of physics students, found that the students knew much physics but did not relate it to the everyday world. They went on to emphasise that this finding has a vital implication for the teaching of physics, arguing that much more attention should be given to integrating the knowledge acquired in school to general knowledge.

This chapter discusses some of the literature relating to difficulties reported when learning physics, most of these relating to failures in conceptual understandings. Specific areas are outlined first, with a review of findings. This is followed by a look at some more general issues. There are few studies which explore the reasons why the difficulties occur, although there is much speculation but the studies which offer some clear indications of the underlying reasons for the problems are reviewed briefly before turning to the area of problem solving in physics, an area which has received considerable attention.

6.2 What are the Difficulties

The literature is full of reports which explore areas where school pupils or university students find problems in learning physics. Most focus on conceptual understanding and are fairly descriptive. Some describe new ways which the authors have developed to reduce the difficulties but very few offer any educational underpinning which might explain *why* the difficulties exist and the kinds of approaches which might, therefore, be more likely to provide solutions.

Peters (1982) demonstrates that previous studies of students' understanding of kinematical concepts have shown that problems do exist with such simple concepts as position and velocity, as well as the more difficult concept of acceleration. One possibility for the origin of confusions is that students have a hazy conceptual framework for describing motion but what is meant by 'hazy' and how this arose is not discussed fully. At best they confuse two concepts, e.g. position and velocity. At worst, students hold views that directly contradict those of the practising physicist. However, that often occurs. They observe that students can apparently learn to grasp and apply the procedures of physics without worrying too much that this may contradict their perception of the real world. Thus, their learned knowledge of physics is compartmentalised and not allowed to relate to the real world around.

Brown (1989) shows that high-school students enter physics classes with pre-conceptions in the area of Newton's third law. These preconceptions are found to be persistent and difficult to overcome with traditional instructional techniques. In addition, students have a naïve view of force as a property of single objects rather than being seen as a relation between objects.

Watts and Pope (1989) notes that Piaget (1929, 1974) was one of the first researchers to comment on children's theories of light. For instance, he notes that, for a six-year-old, light and vision are separate. He suggested that, for young children, light does not actually exist between the source and the effect. However, Guesen (1985) argues that, by age 13 - 14, many youngsters do recognise light as an entity in space and can use this to interpret shadows. Similarly, Wosilit *et al*., (1999) found that the examination questions show that many students do not recognise the critical role of path length (or phase) difference in determining interference effects.

Maloney (1985) reports on a study designed to determine if student difficulties in understanding the interactions of electric charges with magnetic fields might be caused, at least in part, by an alternate conception. Several reasons are proposed for these difficulties. One reason given is that magnetic force situations are three dimensional. A second one is that the right hand rule is an unusual procedure which is often misunderstood. These matters are almost certainly involved, but he argues that there might also be some alternate conception causing students difficulty.

Liegeois *et al*., (2003) explain that the understanding of electricity concepts by young pupils, high school students, and college and university students has been the focus of many studies in psychology and education (e.g. Borges and Gilbert, 1999). The concepts investigated include electric circuits, electricity diagrams, current, potential difference at battery terminals, and resistance and practitioners. A number of misconceptions about these notions are noted (see Chang *et al*., 1998, for a review). One of these misconceptions is the confusion between potential difference and current (Millar and Beh, 1993; Millar and King, 1993).

Liegeois *et al*., (2003) suggest that, from the physicist's view (Psillos and Koumaras 1993), potential difference refers to the inequality of charges between the battery terminals. This inequality of charges results from chemical reactions inside the battery (the separation of positive and negative charges and their accumulation on opposite sides). Potential difference is the origin of electric current, that is, it is the origin of the motion of the free electrons in the conductor to replace the missing electrons at the positive battery terminal. Potential difference, resulting from electrochemical reactions inside the battery has a constant value.

Then, Liegeois *et al*., (2003) looked at situations where pupils were asked to deduce potential difference from resistance and current information. They reveal that their studies showed that most participants (from 8th to 12th grades) only relied on current and ignored or greatly underestimated the importance of resistance information when asked to deduce potential difference from resistance and current information. Furthermore, the experience of electricity lessons did not alter the way they thought very much.

Bowmen *et al*., (1992) interviewed university and high school physics students about their understanding of displacement, velocity, and frames of reference. They showed that the students had insufficient understandings of the concepts. Furthermore, they found there were likely to be significant differences between the ways students address simple, quantitative problems and more qualitative problems based on the same concepts. The problems become easier to solve in a quantitative mode. Presumably, the students had memorised algorithmic procedures which they applied correctly to gain correct numerical answers. This, of course, does not imply understanding of the concepts.

McDermott (1998) looked at student understanding of concepts related to problem solving in mechanics. She found that the students are often unable to apply the concepts although they could solve quantitative problems, the usual measure for student achievement in a physics course. Furthermore, she demonstrated misconceptions about the relationship between force and motion. She also noted that less well documented are difficulties students have in interpreting the relationship between force and more complex concepts, such as work, energy and momentum.

Additionally, Wosilit *et al*., (1999) confirmed that many students who have studied physical optics do not develop a clear model that they can use to predict and explain interference and diffraction effects. They also suggest that what is crucial is that students be given the opportunity to go step-by-step through the reasoning involved in the development and application of important concepts. They also suggested that while the tutorial system was implemented primarily to improve student learning in the introductory course, it has been found that it has helped graduate students and new faculty to deepen their understanding of physics and of the difficulties it presents to students.

The studies mentioned above address specific areas of difficulty. One review has brought together these and many other findings. Zapiti (2001) reviewed the world wide literature on difficulties in learning physics at school level, seeking to identify the areas where difficulties were being observed repeatedly. She found general agreement that the difficulties in physics lie in three main areas:

Mechanics *Electricity and Magnetism* *Thermodynamics*

Specifically, Zapiti (2001) noted that the concept of acceleration proves particularly difficult and there are often confusions between velocity and acceleration. Similarly, the ideas of momentum and kinetic energy are confused, especially in relation to elastic collisions. In addition, the concept of force is often poorly understood and its relationship to motion is a source of confusion, many believing that motion implies a force. She noted another study where force, velocity and acceleration were poorly understood, with unclear relationships between them while studies confirm that the ideas of action and reaction are sources of misunderstanding.

In the area of electricity, Zapiti (2001) found a variety of misconceptions, including: electricity is stored in a battery and may stay in wires; one wire is sufficient between a battery and a bulb; two kinds of current travel in circuits (plus and minus current); batteries are constant current sources while many students can apply Ohm’s Law correctly but do not really understand the concepts involved.

The concepts of heat and temperature are often confused and there seem to be major difficulties in grasping the idea that different objects are at the same temperature when in contact with same surroundings for a long time. In addition, she observed from her review that students simply cannot cope with the differences between the language of science and everyday life and they find it difficult to equate such ideas as *wasting energy* with *conservation of energy*. She also argues that all students need to be introduced to a suitable form of the second law of thermodynamics in order to make sense of the apparent conflicts. Indeed, the concept of energy is poorly grasped and a source of many problems.

Finally, Zapiti (2001) suggested that there are two main sources of problems. The first is perhaps caused by introducing concepts too early when the students are more likely to lack the relevant experience, thus leading to the development of misconceptions. The second main reason why difficulties occur lies in an information processing understanding of learning, because of the limited capacity of the working memory space where information is held and processed. Very often, topics are introduced in such a way that the learner has insufficient capacity to handle all the ideas together, leading to an information overload. This tends to make understanding very difficult. This will be considered further later.

Looking at the review offered by Zapiti, it is very clear that certain topics should not be taught at too young an age. It is inappropriate to introduce ideas of electricity when pupils are too young and, certainly, they should not be taught at primary stages. Similarly, any attempt to teach forces and energy with any hope of understanding at primary stages is almost certainly doomed to failure. Descriptive physics can be taught but conceptual understanding is probably impossible in developmental terms. It has been shown in a similar chemistry study (Garforth *et al.*, 1976) that insecurity caused by the introduction of concepts too early can persist well into undergraduate life.

The work of Zapiti shows clearly that difficulties in learning physics are very likely to affect attitudes and confidence and that this, in turn, will make it less likely that the school pupils will choose to study physics further. This issue is now considered briefly.

6.3 Difficulties May Affect Uptakes

Forg and Wubbels (1987) indicate that physics teaching at Dutch secondary schools has given little attention to the applications of physics, and pupils are not required to carry out many experiments by themselves. This led the curriculum developers to adopt some key strategies. They decided that the new physics curriculum should,

> *"Deal with technical applications of scientific concepts so that pupils, as consumers, would be able to cope with the products of technology in every day situations.*
>
> *Give students the knowledge and skills needed to make thoughtful Judgements on controversial issues in society.*
>
> *Incorporate a variety of technological, academic and / or social contexts in which physics plays a part;*
>
> *Give the students an opportunity to make decisions about the content of the curriculum and about the way they work (differentiation)."*
>
> Forg and Wubbels (1987, p.298)

Stokking (2000) has revealed the success of this kind of approach.

Forg and Wubbels (1987, p.299) also noted that school inspectors in England came to the following conclusions:

> *"(1) Scientific topics need to be introduced through their practical applications and the experience of pupils rather than derived from abstract concepts.*
>
> *(2) The choice of real-life examples should reflect the interests and experience of girls as well as boys. It would be advantageous if physics and chemistry were to be more frequently related to problems where pupils can express an opinion."*

This has never been applied, and the numbers taking physics continue to decline rapidly (from 1965 to 2005, the numbers in England taking Advanced Level in Physics have declined by 35% (Statistics in Education, RSC)

Forg and Wubbels (1987, p. 305) emphasise that the applications that will make physics attractive in general are those which are not only directly visible but can also be experienced by students in every day life. This links strongly to the finding of Reid (1999) when he argues for a curriculum based on applications which are real to the learners in the context of their lifestyles. It is too easy to develop a curriculum which is full of useful applications but these are not 'real' for the learners at their stage of life.

In Scotland, physics has always been popular. Indeed, in terms of uptake, it has been in the top three elective subjects (English and Mathematics can be considered as 'core') at the Scottish Higher Grade since 1962 (Scottish Qualifications Authority, Annual Reports). In the 1980s, a new curriculum was introduced at Standard Grade (ages 14-16) and this was based on an applications-led principle, following the Dutch model. The effect on uptakes in physics at the Higher Grade (the course which follows) is interesting, the transfer rate from Standard Grade to Higher being the *highest* for any elective subject in the Scottish curriculum at this stage (see Reid, 1999), as Figure 6.1 shows:

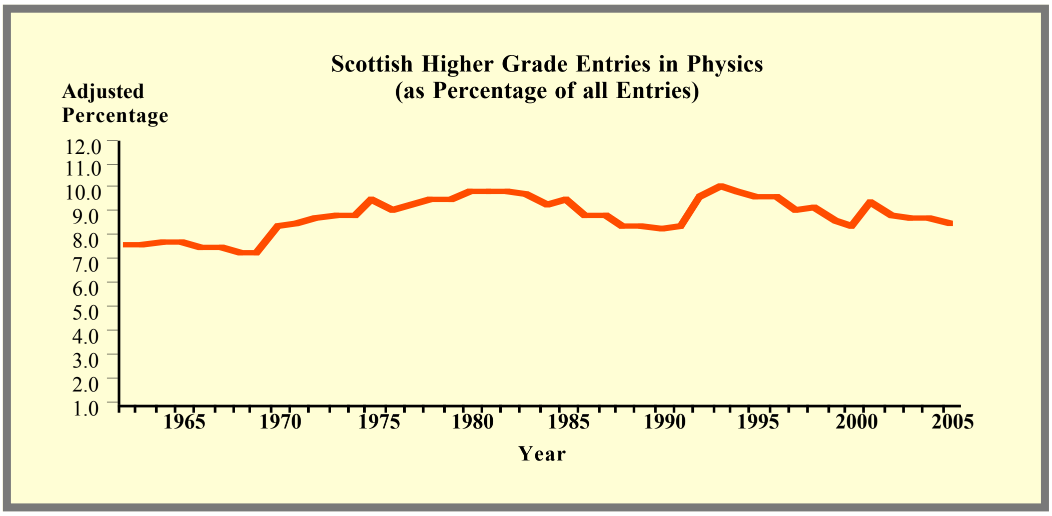


Figure 6.1 Physics Higher Grade Entries in Scotland (1962-2006)

The sharp rise in the uptakes in Higher Physics corresponds exactly with the first few years of completion of the Standard Grade course. A comparison with chemistry which did *not* develop an applications-led course is revealing (Figure 6.2). Skryabina (2000) interviewed many students and this confirmed very clearly what made physics popular.

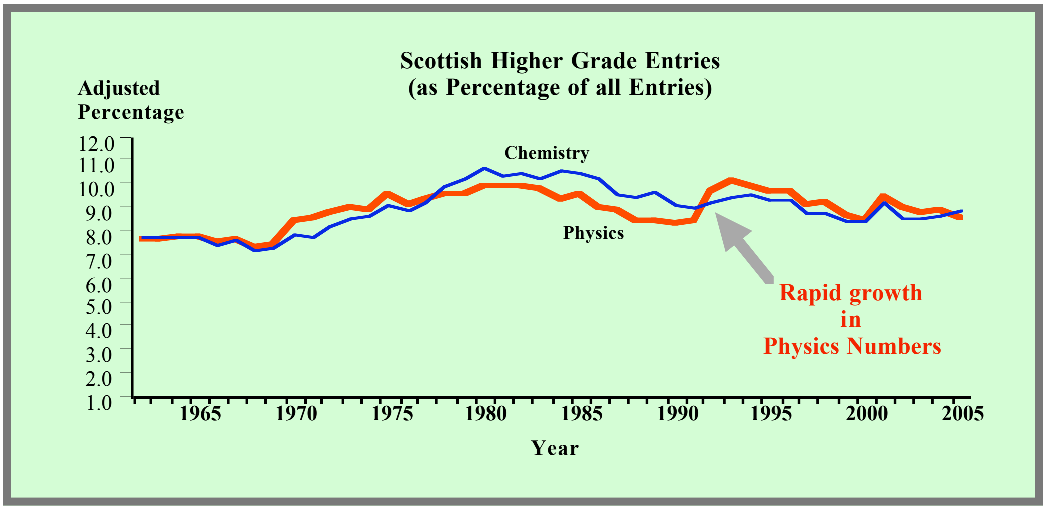


Figure 6.2 Physics and Chemistry in Scotland

Reid (2000) considers possible reasons why chemistry should be studied at school. His arguments apply in a parallel fashion in physics. He argues that the unique contribution of the sciences in a curriculum may be to develop the skills so that the learner can address questions of the physical world in such a way that meaningful answers can be obtained. Following this argument, the curriculum might be based around answers to these questions:

(a) What are the question that physics asks?
(b) How does physics obtain its answers?
(c) How does this physics relate to the lives of the learners?

He presents a simple picture to consider the question about the purposes of teaching physics in terms of the nature of the school population (Figure 6.3).

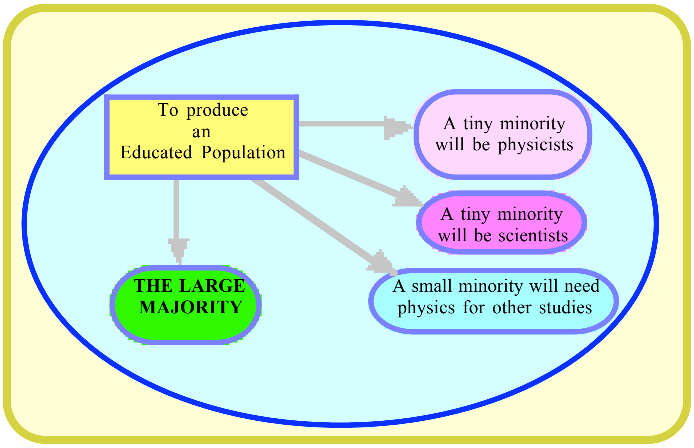


Figure 6.3 Physics and Chemistry in Scotland (derived from Reid, 2000, page 385)

Prosser *et al*., (1996) observed that people who apply physics to everyday situations seem to understand it and learn it more easily. This is a very important observation and is consistent with the findings of Reid and Skryabina (2002a) who showed that the physics curriculum which was based on applications which the learners perceived as related to their life style and context was very powerful in developing positive attitudes (see figure 6.2. The same approach was incorporated, as far as possible, into a senior high school curriculum in chemistry in the Emirates (Hussein, 2006) and the positive effect on both attitudes and understanding was quite remarkable. Such curricula do exist and can be shown to be very successful not only in terms of attitudes developed but also in terms of the sound understanding of key physics concepts. In a sense, this shows physics as a subject which can solve problems and make a real contribution to society.

Reid (1999) indicates that the application of science in life (at a level appropriate to the learner) would define the science content to be taught while the psychological understandings of the way we learn would control the way the material was presented (see figure 6.4)

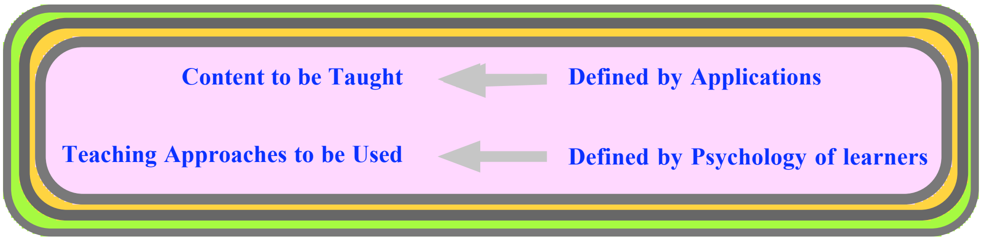


Figure 6.4 Implications of applications and psychologically driven curriculum (Source: Reid, 1999)

Reid (1999) explained a possible way to approach applications by allowing the learners to interact with some real life problem relating to the physics, using this as a starting point to unfold the physics ideas which would be necessary to reach a solution. The Scottish Standard Grade course builds its topics round themes like Space Physics, Medical Physics, Communication .... However, there are two important features that must be stressed: the applications must be relevant to the learners and the applications define the material to be taught. Many curricula *add on* applications to apply the ideas being taught. In a genuinely applications-led approach, the applications *lead* the study and it is important to recognise for a 14 year old school pupil, say, the relevant applications will be very different from the meaningful applications for a first year undergraduate. Indeed, a meaningful application for a 14 year old may vary somewhat from country to country.

It is possible to argue that such an approach lacks rigour and is a poor preparation for further study. The evidence gained by Skryabina (2000) showed very clearly that this simply did not happen. Students were performing extremely well in the Higher Grade Physics (the next course after the Standard Grade), even though the Higher Grade course was found to be excessively difficult. An applications-led syllabus was proving to be an excellent foundation.

Previous work showed very clearly that quality of the curriculum and quality of the teacher were two factors that influenced school pupils to study science subjects (Johnstone, 1972). Recent studies have confirmed this very clearly for physics but have added a third factor (Reid and Skryabina, 2002a): the perceived potential of physics to lead to good employment. If physics is to become attractive again in those countries where it is not popular, then these three factors must be explored. The curricula need to be changed to become more related to life, probably by becoming more applications-led; the teacher qualifications and commitment must be enhanced, probably by increasing their status through extra rewards and resources; the career potential arising through studies in physics needs to be communicated to the learners in attractive ways.

Reid (1999) suggested that science implications might lead to a curriculum structure based on five areas:

1	Historical	How the sciences and society have affected each other.
2	Domestic	How the sciences influence lifestyle.
3	Economic	How the science relate to wealth creation.
4	Industrial	How science has influenced industry and commerce.
5	Socio-moral	The major issues that the sciences generate.

Table 6.1 Possible Areas for the Curriculum (after Reid, 1999)

In an application-led approach, students are introduced to the physics that is needed to make sense of the world around as they know it, giving insight in to the perspective and methods of scientific enquiry as well as its outcomes. The key point is that the actual physics to be taught is determined by the applications used. The real-life problem can define the physics to be taught and may provide the framework for the more traditional teaching that follows (Reid, 2000).

6.4 General Problems

There are numerous research studies which have looked at more general issues related to the learning of physics. Some of these are now considered.

Tobias (1993) noted that the problems in examination questions seldom required the use of more than one concept or physical principle. Usually, students are merely asked to explain or comment as well as complete a calculation. In general, learners are not required, at any time, to interrelate concepts or to try and understand the "bigger picture" solution. Examinations tend to determine the aims of courses and, if the "bigger picture" is not being explored, students will limit their thoughts to the strategies to conduct correct calculations, with occasional comments and interpretations.

The language of physics can also generate problems. Tobias (1993) is aware that "ordinary" words will have special meanings when used in physics contexts and the meanings of some words may be quite different from what they are in other uses. Phrases like "static measurement", "equilibrium", "uniform motion" and "saving energy" may all cause confusions. In a detailed analysis, Cassels and Johnstone (1978) looked at words and language structures which cause problems in science. They identified the use of ordinary words with specialised meanings, 'sound alike' words, and the use of negatives as all causing problems.

Physics tends to rely heavily on the use of mathematics. Very often, the pupils can manage to cope with the mathematics in the mathematics classroom, but find it very difficult to apply the same mathematics in a physics context. This is almost certainly because of working memory overload (Johnstone 1997). Tobias (1993) observed that many scientists believe that the reason science is “hard” for those who do not specialise in it is easily explained by the students’ lack of competence in algebra, trigonometry, and calculus. The problem is not so much matter of competence. Until the mathematical procedures have been so mastered that they become almost automatic, carrying out the procedures takes up too much working memory space, leaving inadequate capacity for thinking about the physics.

A specific area of problem lies in the use of graphical representations. McDermott *et al*., (1987) described two categories of student difficulty that they have investigated: difficulty in connecting graphs to physical concepts and difficulty in connecting graphs to the real world. The specific difficulties in each category are identified and discussed in terms of student performance on written problems and laboratory experiments. In addition, they were given an idea about difficulties in connecting graphs to physical concepts: they found that students generally have demonstrated a fairly good command of the kinematical concept by performance on other problems that do not involve graphs. Thus, most of the errors made by these students can be primarily ascribed to inability to interpret graphs rather than to inadequate experience with the concepts. Again, these difficulties can be ascribed to working memory overload (Reid 2008).

McDermott *et al*., (1987) found problems with the slope and the height of graphs. Thus, when interpreting a graph in physics, a student must be able to determine which features of a graph correspond to particular physical concepts. On a straight-line graph, for example, information may be contained in the co-ordinates of a point, the difference in the co-ordinates of two points (the rise or run), or the slope of a line. Many students seem to need assistance in learning how to choose which of these features to “read” in answering questions about the topic represented in the graph. The students find it more difficult to interpret curved graphs than straight-line graphs. Curved graphs involve changes in slope are as well as changes in height. Students have difficulty in relating one type of graph to another. Likewise, the process of finding displacements by counting the number of squares under a velocity versus time graph requires interpreting areas as length. Students often find it difficult to envision a quantity that they associate with square units as representing a quantity with linear units. They also found difficulty in the task of representing an observed motion on a graph. Moreover, the students also have difficulty in drawing a velocity-time graph that is qualitatively correct for the motion of an object that slows down, turns around, and speeds up in the opposite direction. The situation is even more complicated when not only the velocity, but also the acceleration changes.

When students are facing difficulties, the teacher has difficulty knowing when to offer help. For example, Bolton *et al*., (1997) emphasise, that in a classroom situation, the test for the instructor lies in deciding when help should be given and what form it should take. Leaving students to struggle alone for too long can be demotivating and destroy their confidence. In different words, help that is too specific may not only derive them of much of the satisfaction of solving the problem for themselves, but may by its very nature be demoralising or corrupting.

However, Bolton et al., (1997) suggest that physics should be an ideal subject for the development of good problem-solving schemas, reinforcing the results of earlier experiments by Chi *et al*., (1981, page 180) which demonstrated that one of the main differences between experts' and novices' approaches to physics problems lay in the way in which they categorised problems prior to formal solution. Novices tended to focus on 'surface' features of the problems, whereas experts grouped the problems in terms of the laws corresponding to the solution principle required. Furthermore, Gold (2002) noted that, '*If the teachers help children too much they don't do the thinking*'. He also described '*teachers working very hard and children just waiting for teachers to provide them with the answers'*.

The whole area of conception and misconception has generated a very large number of studies, many of which report the problems with little educational underpinning. In a huge study involving 5000 physics students at 30 institutions, Hung and Jonassen (2006) found that the conceptual understanding of students enrolled in physics courses was unsatisfactory (Maloney *et al*., 2001). However, Peters (1982) found that honours students tend to exhibit similar kinds of misconception as do students in the usual standard introductory courses. This is very typical: misconceptions are difficult to correct and students can often operate with misconceptions while ignoring these to solve physics problems successfully by the taught methods.

Most of the studies used to investigate these difficulties consisted of asking certain kinds of written questions and inferring from the responses the level of understanding that the students had. Peters (1982) suggests that a student should be able to approach a physical concept from all directions, from the observable phenomena to the verbal, symbolic, and mathematical representations of that concept. The student should be able to describe what a concept is not as well as what it is. The student should be able to distinguish between closely related concepts, noting their similarities and differences. This is the mark of a very high level of conceptual understanding.

The place of the experimental also causes problems. Thus, Carey *et al*., (1989) note children's dramatic failures both at designing experiments to discover causal mechanisms and at interpreting experimental data. As many authors suggest (Inhelder and Piaget 1958, Kuhn and Phelps 1982, Kuhn et al., 1988), one source of these failures is children's lack of metaconceptual understanding of the distinction between theory and evidence, and, between the goal of understanding a phenomenon and the goal of producing a phenomenon.

6.5 Do Boys and Girls Understand Physics Differently?

> *If someone tells you that woman cannot do science, or are not as good as men, that is not true, women are different, and science needs different perspectives, and women can provide valuable, different perspectives to science."*
>
> Seymour and Hewitt (1997)

The issue of gender and physics has often been studied. In most countries, it is observed that the number of boys taking physics exceeds the number of girls by a large margin. There might be two possible reasons for this: either physics is simply a subject which appeals more to boys or the way physics is presented is more attractive to the boys.

Much of the research is descriptive, describing the problem, and then going to make assertions about the possible answer. There are few studies which offer useful insights into the reasons for the problem.

Huffman (1997) asserts that previous research indicates that, in high school physics, male students generally make larger gains in conceptual understanding than female students. Heller and Lin (1992) found that, in high school, male students made significant gains in conceptual understanding while female students did not appear to have learned anything in their high school physics classes. He suggested that motivation was a factor but that offers little insight into a useful way forward.

Numerous studies have demonstrated the greater interest of boys towards physics while the life sciences appeal more to girls (eg. Schibeci, 1984; Gallager, 1987; Craig and Ayres, 1988; Weinburgh, 1995; Farenga and Joyce. 1999). Girls are more person-oriented, socially responsible, friendly and cooperative, while boys tended to be more independent, achievement-oriented and dominant (Smithers and Hill, 1987). They go on to observe the findings that girls who choose physics tend to be more intelligent, to have a distinctive temperament, and are less person-orientated as compared with the other girls and are more likely to be convergent thinkers.

Stadlert *et al*., (2000) also noted that boys achieve higher grades in tests and are more interested in learning physics then girls (Mullis et al., 1998; Hoffmann *et al*., 1998). He indicated that girls seem to think that they understand a concept only if they can put it into a broader world view. Boys appear to view physics as valuable in itself and are pleased if there is internal coherence within the physics concepts learned. Moreover, Stadlert *et al*., (2000) suggest that the contexts that are meaningful for girls are usually also meaningful for boys but that there are also significant differences between behaviour, their working methods and their use of language (Gilligan 1982). Stadlert *et al*., (2000) summarise the way boys and girls respond to the teacher in physics lessons (table 6.2).

How boys and girls respond to the teacher's questions

	Boys	Girls	Type of Question	Example
Closed Questions	more frequently answered	less frequently answered	Part of the thematic pattern given by teacher	Teacher expects one possible answer.
Open Questions	less participation	strong participation	More like real questions compared to daily life	Why does the pendulum move like that?
Clipped Telegram Style	more frequently, using half sentences, using technical physics terms, self-assured in physics.	less frequently, using complete sentences, not using technical terms but drawing on vocabulary from everyday language, limited self-confidence in physics.		
Roles and Behaviour	take control, use more imperatives and instructions, look for concrete solutions to a problem, move into the framework of science, use scientific terminology.	tend to take notes tend to be more passive look for possible fields where they might find a solution, such as, physics, day to day knowledge and use morphism		

Table 6.2 Answering Questions: boys and girls (derived from Stadlert *et al*., 2000)

Jorg *et al*., (1990) in Stadlert (2000) showed that male and female students already differ in their interest towards physics considerably at the beginning of second grade in secondary school (at age 13). Stokking (2000) also notes that many studies have shown that female and male students make different choices: male students more physics, female students choose more biology (for example, Kelly, 1988, Rennie and Parker, 1993). In the Netherlands, specifically, in higher general secondary education, the percentage choosing physics was more then 50% for male students and almost 15% for female students, and pre-university secondary education more than 60% and almost 30%, which is comparable to the percentages found by Kelly (1988) for England. Stokking (2000) also notes that, in Oakes (1990) in the USA, it was found that male students were more interested in things, while female students were more interested in people.

Stokking (2000) found that, on average, female students scored significantly lower than male students on interest, future relevance, appreciation, clarity, self-confidence and marks for physics; and higher on difficulty. Furthermore, Woolnough (1994) noted that boys are more likely to have benefitted from early physics experiences than girls.

Skryabina (2000) observed from her study that physics may be more attractive to girls if the content of physics lessons reflects the interests of girls. She found that boys and girls had equal areas of interest in topics relating to physics but their interests did not always coincide. In most studies, a general trend is that girls are less interested in physics than boys (eg. Graig and Ayres, 1988; Weinberg, 1995; Ramsden, 1998). Nonetheless, this could simply be being caused by the topics being covered in the physics syllabuses being followed. If the physics curriculum is designed mainly by men, then it is highly likely that the themes and illustrations would arise from male-orientated interests. This point was made eloquently by Skryabina (2000) and Reid and Skryabina (2002b).

The Skryabina (2000) study confirmed that boys had a greater interest than girls in physics topics related to technical objects and the way they function as well as in physics as a 'scientific enterprise' while girls were found to show greater interest than boys in physics in the context of its impact on society. Almost no differences have been found in the interests of boys and girls in physics topics related to explanations of natural phenomena and understanding how physics can serve mankind.

The work of Skryabina suggests that the gender problem rests largely with the way physics is presented, or, perhaps, the way the girls perceived that it is presented. Physics, by its very nature, has a very direct relationship to lifestyles and to the way societies have developed. It is very much related to people. However, if it is presented as an abstract conceptual subject, then its human dimension may be lost and this is of greater importance for the girls.

6.6 Explaining the Problems

While there are huge numbers of studies which show the problems associated with the learning of physics, attempts at seeking answers about why these problems exist are much less frequent. The work of Johnstone stands out but much is derived from his work in chemistry (see Johnstone, 1997). His work shows a sustained exploration of the whole area, the development of hypotheses and the subsequent testing of these in action in numerous circumstances.

Johnstone started by looking at difficulties in learning chemistry (Johnstone *et al*., (1971, 1974) but soon moved into physics (Johnstone and Mughol, 1976, 1978, 1987). An early hypothesis to explain the reason for the difficulties then followed (Johnstone and Kellett, 1980) and this hypothesis was tested (Johnstone and Elbanna, 1986, 1989). Reviews followed later (Johnstone, 1991, 1997) while the hypothesis was further tested in areas of physics and found to hold true (Johnstone and MacGuire, 1987; Johnstone *et al*., 1993, 1998).

He observed that topics which were known to be causing difficulties were those where the learner had to hold or use large amounts of information *at the same time* in order to reach understanding or arrive at a solution. This meant that the amount to be held and processed exceeded the capacity of the working memory. Most frequently, this meant lack of success. His approach is related closely to the work of Miller (1956), Anderson (1983) and Baddeley (1986). He used the hypothesis to predict when and where failures would occur (see Johnstone and Elbanna, 1986, 1989, for examples of his approach). His work is highly reproducible in numerous areas of the curriculum and levels of learning (see: Sirhan *et al*., 2001; Danili and Reid, 2004; Christou, 2001; Bahar *et al*., 1999 ; Hindal, 2007). His model of learning was highly predictive and others have used it to bring about quite remarkable improvements in learning (eg. Danili and Reid, 2004; Hassan *et al*., 2004; Hussein, 2006; Chu, 2007).

The limiting capacity of working memory space offers an explanation for the areas of difficulty in physics, all of which seem to involve the holding of much information *at the same time* in order to gain understanding. This is typical of highly conceptual areas where, to grasp the concept, many ideas have to be held at the same time. It also explains why language can pose problems. A very revealing study carried out in Botswana showed clearly the effect on working memory of working in a second language (Johnstone and Selepeng, 2001). For many learners, physics requires the use of new words. The working memory also explains why graphical representations and analogies can sometimes cause confusion and, indeed, why mathematical ideas are not transferred effectively into physics situations. All of these can generate working memory overload.

Setting a physics problem using words plus a diagram can be seen as a way of reducing overload, perhaps by considering the diagram as a chunking device (Miller 1956, Simon 1974) or possibly related to a temporary visual store (Baddeley 1986). Equally, the use of the visual may cause overload (Jumailly, 2006). The aim of examination question is to test physics. However, Johnstone *et al*., (1993) found that the form of the question is important. In some forms, it is possible that the question does not so much test the physics but a psychological artefact such as working memory space or field dependence. These are important considerations for those who set examination questions.

This leads on to the idea of field dependency. The early work was conducted by Witkin *et al*., (1974) who emphasised that some learners have more difficulty than others in separating 'signal' from 'noise'. These are classed as field dependent. Similarly, Johnstone *et al*., (1993) found evidence that a physics problem can be presented in such a way as to reduce the noise input to the processing system and, as a consequence, allow greater success for all groups but particularly for field-dependent groups. The 'noise' can be thought of as the information which is not central to the task in hand.

The skill of being able to see what is important for a particular task and disembedding it from the surrounding information is highly correlated with success in examination performance in many subject areas including physics. Research has not yet shown clearly if and how this skill can be developed (see Danili, 2004). If a person has an above average working memory capacity, then the extra space can compensate for being field dependent (not good at separating message from noise) (Johnstone and Al-Naeme, 1991; Christou, 2000, Danili and Reid, 2004). In a large study at school level (age 13) across several disciplines, Hindal (2007) showed that working memory capacity and extent of field dependency both affected examination performance even when recall of information was the key skill to be tested. In a review, the impact of working memory capacity on learning was clearly demonstrated by Kirshner *et al*., (2006) from a very different perspective.

Thus, a necessary (but not sufficient) condition for a student to be successful in understanding or in an examination question is that the demand of the question should not exceed the working memory capacity of the student (Johnstone and El-Banna 1989). If the capacity is exceeded, the student's performance will fall unless he has some strategy which enables him to structure the question and to bring it within his capacity. It is a very heartening feature in that when their capacity is exceeded, about 10% of students can still continue to function successfully. In other words, strategies can be learned which enable a learner to overcome capacity limitations. Thus, it might be possible to describe a person who is successful in physics as one who has developed a good set of strategies in that subject and who has learned to operate well within his/her working memory capacity.

This also raises the question about how to improve the performance of the other 90% . Can strategies be taught? The evidence is not encouraging although there are some interesting ideas arising from cognitive acceleration work (Adey and Shayer, 2002) although they never discuss working memory capacity at all. What can be done is to re-structure teaching and learning in such a way that working memory overload is reduced and this generates a quite remarkable performance improvement (see, especially, Hussein, 2006)

Prosser *et al*., (1996) indicated that different people have different capacities for different activities:

> "*Some people try to understand the concepts involved rather than just memorise equations ..... Some people can understand things more easily and are able to relate new ideas to previous ones. Others find that they cannot understand the fundamentals and give up, therefore not being able to understand more complicated ideas.*"

This illustrates an important point. If memorisation of information (without necessary understanding) is acceptable (or encouraged), then the working memory capacity problem is reduced considerably in that information is just passed through the working memory to be stored in long term memory. However, that information may be difficult to recall after a reasonable time period and, when faced with a novel situation the learner may not be able to apply their knowledge effectively simply because they have never understood the ideas.

Hung *et al*., (2006) stress that the core properties of physics and other sciences are causally related in nature (Carey, 2002; Keil, 1989). These causal relationships determine the functional properties of concepts in physics and other scientific domains. That is, conceptual knowledge is *"an understanding of the scientific parts and cause-effect relationships that exist within a system"* (Guentler, 1998, p.289). This offers another insight. Piaget (1962) showed very clearly that causality and hypothesis formation are skills which develop in the final stages of cognitive development (approximately ages 12-16). If physics is taught too early in terms of causality and hypotheses, then there may be developmental problems (probably caused by the growth of working memory with age), then understanding may be a problem.

The use of group work has sometimes been suggested as one way to reduce problems. Working in a small group offers the capacity of several working memories when facing some problem task. Although the working memory is the property of an individual, it is possible for several to work together, reducing potential overload (Reid and Yang, 2002b).

Malacinski (1994) suggests ways to reduce difficulties which seem to reflect this:

(1) Teaching should emphasise the education of students to be critical thinkers and productive citizens in the information age.
(2) Collaborative learning strategies are effective formats for developing the thinking skills necessary for the problems they face.
(3) Teamwork and verbal communication skills, both of which are highly valued in an information society (Reich, 1991).

He indicates that collaborative learning groups provide an ideal structure for students to 'unwrap' new information, construct understanding, develop critical thinking skills. An environment of peers encourages questioning, evaluating, and criticising.

Malacinski (1994) notes a meta-analysis by Totten (1991) of the results of over 600 research studies supporting the thesis that the more a student works in a learning group, the better that student learns, the better the student understands the content, and the more easily the student remembers the content.

Then, Hung *et al*., (2006) suggests, that by providing students with explanations for the concepts of force and motion before the students observed the phenomena, students were better able to make correct interpretations (Chinn and Malhotra, 2002). Also, Furib *et al.,* (2000) indicates that a good teaching of any subject firstly calls for teachers to have a high grade knowledge of the concepts and theories of the discipline she/he is to teach. Woolnough (1994, page 370) argues that one key to attract students towards physics depends on high quality physics teachers: they should be well qualified and have the time and the inclination to give personal encouragement to their students. Another key lies in making it enjoyable with a measure of success. Learners need opportunities to be involved in their own learning and the course should be relevant to the students and intellectually stimulating. In addition, Woolnough (1994) asserts that the parents are a positive factor to encourage the students to join in scientific and technical activities, and to gain confidence in practical problem-solving. All this can be summarised by saying that a student will learn physics better when it is taught better, by a qualified teacher, in a supportive environment: this does not take things forward much!

The whole question of problem solving is now considered.

6.7 Physics Problem Solving

Problem-solving ability is widely regarded as a core skill in the physical sciences, technology and applied mathematics. Despite this, there is often little agreement as to what constitutes a problem. Most work assumes that problems in physics are the kinds of tasks and exercises where students use formulae and relationships correctly to gain correct numerical solutions to calculations. However, problem solving is much more than this.

Glover *et al.,* (1990) noted that most significant real-world problems are ill-defined. Such problems also tend to be more multi-faceted and open-ended and they rarely have a single or final solution, most of them only having a variety of possible approaches rather than an exact outcome. Thus, there is a need for students to gain experience by studying these kinds of ill-defined and more open-ended problems.

Sadly, unlike real-life problems, most problems presented at school (and university) tend to be well-defined. This kind of problem is probably just an exercise. Hayes (1981) defined a problem as what exists "*whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap*". This approach suggests that, if the student knows what to do when given a task, it is an exercise not a problem. In similar vein, Wheatley (1984) defined problem solving as "*what you do when you don't know what to do*".

The confusion over definitions is illustrated by considering the guidelines set out by the Scottish Qualifications Authority (1997). These are defined in terms of abilities:

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

Although each of these abilities is often required in problem solving, this list cannot be taken as the set of abilities which can enable a student to undertake any possible problem solving. There are major gaps: thus, selecting procedures implies that procedures are known. However, in most open ended problems, procedures need to be developed. The list is very inadequate.

The difficulty is that there is a lack of clarity in definitions with some assuming that problem solving is the the successful completion of the tasks in finding answers to numerical exercises in physics while others list a set of abilities which are rather vague and difficult to measure.

Others have tried to define problem solving in terms of the procedures which students can use to gain success. Thus, Greeno and Simon (1978, 1988) suggested a four-part typology of problems:

"(1) Problems of transformation: the problem-solving process was described as "searching through a set of possibilities."
(2) Problems of arrangement: they were regarded as design problems and the problem-solving process was described as "narrowing the set of possibilities."
(3) Problems of inducing structure: the problem-solving process was described as finding "a general principle or structure."
(4) Evaluation of deductive arguments: they viewed that "psychological analyses provide no evidence for a belief in deductive reasoning as a category of thinking processes different from other thinking processes."

Heller and Lin (1992, page 555-556) describe a detailed five-step procedure to solve real-world, context-rich physics problems rather than simple textbook physics problems and describe this as an explicit strategy.

Step 1 is to focus on the problem, and think of a general approach that can be used to solve the problem.

Step 2 includes three parts:
- (a) a physics diagram
- (b) a definition of variables including a target variable, and selection of quantitative relationship,
- (c) the physics principles or mathematical relationships that can be used to solve the problem.

Step 3 is to plan the solution. In this step, the physics description is translated into specific mathematical equations which are used to solve the problem.

Step 4 is to execute the plan. The equations are combined algebraically according to the plan, to produce an equation with a single unknown target variable.

Step 5 is to evaluate the solution. The solution is checked to ensure that it is properly stated, reasonable, and complete.

The real difficulty is that the evidence shows very clearly that students of all ages simply do not follow strategies like these in solving problems. The work of Yang at school level (see Reid and Yang, 2002) and Bodner (2003) at university level leave no doubt that the way students approach open ended problems is very different from the kind of strategies which are often proposed by educators.

A real new insight was offered when Johnstone (see Wood and Sleet, 1993), in a preface to a book entitled "Creative Problem Solving", realised that *all* problems in *all* areas of life had three features in common. He described these three features as: the data provided, the method to be used and the goal to be reached. This fits a simple physics exercise in an examination paper where information (often numerical) is provided, a task has been set for the student and the method has been taught to the student. It fits the kind of problem described by Yang (2000) when she asked students to find out which would give more energy when fully combusted: a kg of coal, a kg of oil, or a kg of gas. Equally, it fitted the very open problem described in the book by Wood and Sleet (1993) when they asked students to estimate the number of amino acid units which were being incorporated in a human hair per second as the hair grew. However, the Johnstone approach works just as well for a car mechanic faced with an engine which will not start or the mother deciding what to prepare for dinner.

By looking at the extremes where each variable is either known or unknown, Johnstone came up with eight problem types (Table 6.3).

Type	Data	Methods	Goals	Skills Bonus
One	Given	Familiar	Given	Recall of algorithms
Two	Given	Unfamiliar	Given	Looking for parallels to known methods
Three	Incomplete	Familiar	Given	Analysis of problem to decide what further data are required
Four	Incomplete	Unfamiliar	Given	Weighing up possible methods and goals then deciding on data required
Five	Given	Familiar	Open	Decision making about appropriate goals. Exploration of knowledge networks
Six	Given	Unfamiliar	Open	Decisions about goals and choices of appropriate methods. Exploration of knowledge and technique
Seven	Incomplete	Familiar	Open	Once goals have been specified by the student, these data are seen to be incomplete
Eight	Incomplete	Unfamiliar	Open	Suggestion of goals and methods to get there; consequent need for additional data. All of the above skills

Table 6.3 Classification of Problems (source: Johnstone, 1993)

Type 1 and 2 can be regarded as the typical problems usually given in textbooks and examination papers. Type 1 is of an algorithmic nature and can be regarded as an "exercise". Types 3 and 4 are very different, with type 3 seeking data while type 4 requires very different reasoning from that used in types 1 and 2. Type 5 to 8 have open goals, and are more like real life problems. However, these are not necessarily more difficult than any other type. In fact, Johnstone never intended that the eight types would be seen as hierarchical. Thus, he did not imply that anyone proceeds from type 1 to type 8 as a kind of development in problem solving skills.

The elegance and simplicity of this approach offers a language which can be applied in any area of enquiry and this approach has been adopted in several research studies (eg.

Bennett, 2004; Reid and Yang, 2002a, 2002b; Al-Qasmi, 2006) offering a simple way to classify problems. One immediate outcome of the classification is to distinguish clearly between the algorithmic exercises of normal examinations and tests from the more realistic problems which are met in daily life. In her study, Yang (2000) found evidence that the Johnstone model is, in fact, *not* hierarchical: in other words type 1 and 2 problems are not necessarily easier than problems further down the list. They are simply different. Other features determine difficulty levels.

The model provides a clear distinction between what are often called closed problems and those which are open ended. Huffman (1997) distinguished between closed problems (typified in physics by those to which there is a unique mathematical solution) and open problems (to which there is no single correct answer), suggesting that problem solving is a complex, multi-layered skill, and not one that most students can be expected to develop unaided. However, he went on to argue that teaching explicit problem solving strategies would assist students in solving problems but this argument has not been found to be true (Reid and Yang, 2002; Bodner, 2003).

Huffman (1997) suggested that previous research indicates that explicit problem solving instruction can help to improve students' problem-solving performance more than traditional instruction (Mestre *et al*., 1993. Heller and Reif 1992; Van Heuvelen, 1990; Wright and Williams, 1986; Heller and Reif, 1984; Larkin and Reif, 1979; Reif *et al*., 1976). However, there is weakness in this argument. It is likely that instruction will aid problem solving simply because it offers the students *more experiences* of problem solving. Traditional teaching will encourage a different strategy in learning for the students who will often resort to the memorisation of algorithms which they find will give 'right' answers. This is the weakness of much argument: it considers only those types of problems which are essentially algorithmic and they are basically exercises. The work of both Yang and Bodner address open problems of types 3 to 8 in the Johnstone model.

Others have argued for various approaches to develop problem solving skills. Thus, Holbrook *et al*., (2005) consider that solving problems in any discipline is very often aided by the use of conceptual models. These models act to provide a framework for understanding the concepts or processes involved in the problem. They also help one to think more clearly about the problem and may provide an appropriate pathway towards a solution. However, this does not offer a clear strategy for teaching.

Larkin (1983a) claims that representations are one of the most crucial aspects of problem solving, because they can determine the direction of the entire solution. Diagrams can be useful because of the way they help organise information into chunks that can be used in the problem solution (Larkin and Simon, 1987). Styer (2001) takes a similar line and argues that students should be encouraged to show their reasoning and not just give the final numerical answer. Such strategies may aid some learners in some problems. However, they are not necessarily a universal approach. Indeed, the best students may simply refuse to show reasoning, their approach often being idiosyncratic (see Reid and Yang, 2002a; Otis, 2000).

Much of this is a feature of what Tobias (1993) described when he suggested that, in solving problems, the student is expected to do the work the way the instructor wishes. This reflects the ways the instructor finds helpful and these may simply not suit many students. Here is one place where students should not be forced to conform.

Bolton *et al*., (1997) are aware of this when they emphasise, that in a classroom situation, the test for the instructor lies in deciding when help should be given and what form it should take. Leaving students to struggle alone for too long can be demotivating and destroy their confidence. However, too much intervention may have an equally bad effect in not permitting the development of those creative approaches which will prove most fruitful in the long term.

Going even further, Shanxi (2002) argues that solving problems in science requires a student to explore his or her repertoire, to imagine a variety of routes to a solution, and frequently to create novel combinations of knowledge or novel techniques for a solution. This is the justification for considering scientific creativity as worthy of attention in the education of students who will either become scientists or who need an understanding of the way that scientists work as part of their general understanding of society.

Indeed, Larkin and Reif (1979) have generally agreed that problem solving cannot be easily taught. This is a matter of concern in that problem-solving ability is widely regarded as a core skill in the physical science, technology and applied mathematics (Bolton *et al*., 1997).

6.8 What is Known about Problem Solving: a Summary

Reid and Yang (2002a) reviewed the literature which described studies relating to problem solving. They discussed the findings in some detail and they identified a number of key issues which were important in considering problem solving success. They then went on to bring together the findings under five headings.

(1) Procedures and Algorithms
(2) Long Term Memory
(3) The Working Memory
(4) Confidence/experience/expectations
(5) Psychological factors

They show that the evidence suggests that, while procedures and algorithms have some place, their value is very limited. This is because using an algorithm is *not* the same as understanding. Thus, such an approach rarely helps when moving into a new situation (implied by any open-ended problem). They suggest that procedures are of limited value in genuine problems and that many of those in the literature are simply too complicated, causing working memory overload.

They observed that the learner facing an unfamiliar problem is essentially undertaking the same process as in learning itself. Thus, what is already known will influence the way the problem solver looks at the new information but it is important to note that information already held may have been learned in one context that may not necessarily neatly be applied in another. They observe that, "*The successful problem solver needs essential knowledge but the way that knowledge was learned will also be very important*" (Reid and Yang, 2002a).

They note the vast amount of evidence showing that working memory capacity may well be a rate determining step in much problem solving. The working memory space is needed to hold new information as well as accept information already held in long term memory besides offering space to process information. The experienced person can use all kinds of approaches to chunk, thus reducing pressure on the limited space. The inexperienced learner does not yet have such strategies and overload is highly likely (See Miller, 1957 and Johnstone, 1997).

Reid and Yang (2002a) go on to note that there are factors which are not essentially cognitive. They identify confidence as one. They observe that "*experience, especially successful experience, builds up confidence*". Of course, this raises the question about how confidence can be developed and it is likely that experience of success (along with productive failure) will be useful. In a later study, Oraif (2007) explored academic confidence and found that this was, indeed, tightly linked to success in the past and that it was largely unaffected by other influences.

Reid and Yang (2002a) go on to consider various cognitive characteristics like the extent of field dependency, extent of convergency-divergency, and the ability to develop representational skills (both mental and physical). While extent of field dependency is observed as very important, they suggest that divergence will be important. In a later study Al-Qasmi (2006) showed that this was, indeed, the case.

Reid and Yang (2002b) carried out a major project in which they looked at the way pupils aged from 14-17 solved highly open-ended problems (Types 3-6 in the Johnstone model) in school chemistry. Yang designed a set of 14 new open-ended problems, attempting to gain some initial insights into the ways pupils solve open-ended chemistry problems. These open-ended problems were designed to relate tightly to the school syllabus, to be used as group exercises and were specifically constructed so that working memory demand was not an issue. Speaking of lack of success in problem solving, Johnstone (2001) has found that, "*in almost every case, an explanation for this failure can be found in information overload...*". In the Reid and Yang study, the aim was to explore the role of long term memory in solving such problems.

The pupils worked in groups of three attempting to solve the problems and were encouraged to talk freely, to make notes of their progress, and to note their agreed answers. Evaluation sheets were also completed individually by the pupils after each problem. The researchers studied the pupils' notes and 'doodles', observed the groups, analysed various evaluations (which included word association tests) and analysed audio recordings of many groups as they worked. Much of the vast amount of data revealed little new but some important new insights were gained in a number of areas.

They made the following deductions from their evidence:

"(a) It is essential to have the appropriate knowledge which must be linked correctly in long term memory and be accessible.

(b) Knowledge seems to exist in long term memory as "islands" and school pupils of this age (14-17) have great difficulty in forming links between the 'islands' unaided.

(c) Links in long term memory have to be made in both directions to be applied effectively. Inappropriate links may lead problem solvers in wrong directions.

(d) When facing such open-ended problems, there is a strong unwillingness or inability to plan. These may be a feature of the lack of key links between "islands" of knowledge. The pathways are not there and the pupil cannot see the logical steps towards solution." (Reid and Yang, 2002b)

They observed that the pupils really enjoyed the problems and worked extremely well in groups, seeming to thrive in debating issues relating to chemistry. They also observed that, "*after trying their first problem, they tackled subsequent problems with increased enthusiasm and what appeared to be increasing confidence*".

However, Reid and Yang (2002b) did raise some important issues:

> *"Where problem solving is not simply dependent on the application of familiar procedures to familiar situations, pupils not only need to have the requisite knowledge in an accessible form, they must also be able to bring items of knowledge and experience together in a meaningful way. This poses the questions about whether problem solving is a skill which can be taught. Furthermore, is it a generic skill ?"*

The idea of links between ideas held in long term memory as a prerequisite for success in problem solving is consistent with the findings of Kempa and Nicholls, 1983). They go on to make the important point that, "if the formation of key links between "islands" of knowledge is a key skill ..... then it seems likely that problem solving is very much *context dependent*." (italics theirs). Reid and Yang (2002b) pick up this idea and raise the question about whether the skill of linking ideas can be taught or whether it just grows with experience:

> *"Perhaps the individual with such links is confident and is willing to take risks to develop new links. Indeed, it may be that confidence is developed from experience, especially successful experience. The person may be willing to take cognitive risks, given a background of successful experience."*

This might explain the observed increase in confidence after successfully completing the first problem.

They argued that there is no evidence that problem skills in one subject area will be transferred to enhance problem solving skills in another. They go on to suggest that:

> *"The observation that it is the formation of links between 'islands' of knowledge that seems to be one important feature of successful problem solving offers an explanation for the lack of transferability of problem solving skills."*

This raises all kinds of questions about teaching problem solving, challenges the supposed generic nature of problem solving skills and reveals that teaching learners strategies may not be a helpful way forward at all.

A later study by Al-Qasmi (2006) picked up many of the ideas from Yang and Reid (2002a,b) and, in a long series of experiments based on problem solving skills with first year university biology students, she showed that it was highly likely that it was the number of accessible links between ideas held in long-term memory which was one key determining factor influencing problem solving success.

6.9 Conclusions

Physics is known to be a difficult subject and it is often particularly unattractive to girls. Yet, the production of those well qualified in physics is often seen to be important for all developed or developing societies. The real question which has to be considered is: why do we teach physics in the school at all? Another way of putting this is what difference does it make if physics is removed from the curriculum completely? Is it not possible to leave physics entirely for the universities? What is it that school physics can achieve which is so important?

If the aim is simply to produce 'experts' in physics, then it is difficult to justify its place in the school. However, if the aim is to educate all school pupils so that they can play an effective role in society, then physics has a vital place in general education. This has to be so in that developments from physics have brought about developments in society of enormous importance and are likely to continue to do so in the future. Every student must be educated in physics simply because all are going to be citizens and the impact of physics on daily life will continue to grow. The school student needs to understand the impact of physics on lifestyle, society and economies; the school student needs to understand the way physics works, its strengths and weaknesses. The key is 'understanding': the student is not well educated unless they have grasped some of the basic ideas of physics and can see their importance in making sense of the world around and changing life patterns for societies: anything from the communications revolution, to travel, to energy problems.

This leads to another important argument for physics being taught to everyone at school level. All students need to understand the way physics asks questions and seeks answers: the way experimentation is used, the way evidence is gathered, the way models of understanding emerge. This is part of scientific thinking.

Too often the sciences are presented as bodies of facts to be mastered. Physics involves a way of thinking and this way of thinking has brought huge advances to the human race as some of the secrets of the way the world works have led to practical developments of considerable benefit (as well as some of dubious benefit). Indeed, Haussler (1987) reminds us that the physics taught should be a connection to our society as a whole, including controversial issues.

Much of this challenges traditional syllabus construction at school level as well as typical ways of teaching. The applications-led syllabus has been discussed and the evidence supports its power in making physics more accessible and attractive to students, especially the girls. However, there is still the question of subject difficulty. Many of the ideas for physics are abstract and they require the learner to handle many ideas *at the same time* in order to achieve understanding. The pioneering work of Johnstone has shown again and again the limitations of working memory capacity as the rate-determining step in much conceptual learning.

This means that certain topics should not be taught at too young an age: topics like forces, energy and much of electricity should be left until the students have developed sufficiently, perhaps around age 14-15. It also means that the way of teaching has to be adapted. The work of Danili and Reid (2004) and Hussein (2006), all in chemistry, have shown that this is possible, with quite remarkable improvements in performance as well as attitudes. There is a real need to develop parallel research in physics. This will involve changes in textbook presentations, examinations, as well as teacher approaches. The remarkable feature of the Hussein experiment was that it required no training of teachers. However, if examinations go on rewarding correct recall of facts and procedures, then any attempt to focus on understanding may well be undermined.

In Scotland in 1962, a new syllabus in physics for pupils from age 12 to 17 was introduced (Circular 490, 1962). This syllabus deliberately rethought physics to aim at understanding and application. The outcomes were most encouraging: physics is extremely popular in Scotland. Long ago, Piaget (1962) argued that the young learner was trying to make sense of the world around. This is the natural way children learn and it can be seen in the curiosity of primary school children. This Scottish syllabus aimed at the understanding of ideas of physics and this is consistent with the natural way the young person seeks to learn. People are satisfied when things make sense and especially when a school subject shows how the ordinary events of life can be interpreted. It makes sense and allows them to apply ideas.

Nickerson (1985) argues that education should produce people who are good thinkers in the broadest sense of the term: people who are not only effective problem solvers but are characteristically reflective; people who are inquisitive and who are eager to understand their world; people who have an extensive repertoire of formal and informal tools of thought and know how and when to use them; people who know a good bit about human cognition and how to manage effectively their own cognitive resources; people who are disposed to be actively fair-minded in their seeking and use of evidence. Physics education has its part to play in developing such people. It is not necessary to worry about producing good physicists: any education in physics which is designed this way will generate a very good supply of qualified physicists as the Scottish experience reveals (see Skryabina, (2000) in her survey of the numbers and qualifications of first year university physics students)

Reid has suggested ways by which a curriculum can be specified (Figure 6.5).

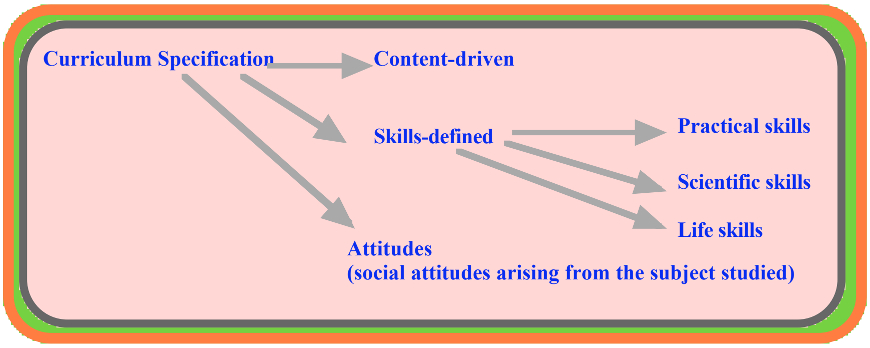


Figure 6.5 Curriculum Specification (after Reid, 2000)

So often a physics curriculum has been content driven in its construction, the content being determined by the next stages of study. This chapter has argued that this is not the best way forward. The recent monograph by Mbajourgu and Reid (2006) has summarised the literature on physics education and offered a specification for a physics curriculum at higher education level. Much of this is easily applicable at school level. One important underpinning principle of any physics curriculum is the development of those thinking skills which can be called 'scientific thinking' and this is the focus of this study. The next chapter will consider what is meant by such skills.

Chapter Seven

Scientific Thinking

> *"The challenge is not so much to teach thinking as to teach good thinking."*
> *Nickerson (1985)*

7.1 Introduction

> *"All young people, not just those intending to follow careers in science, must be scientifically literate. They need to have a good knowledge and understanding of science and scientific ways of thinking in order to function effectively in a global and evolving technological society. They also need to have the skills and critical awareness to interpret and make sense of what they see and read about science in the media, where messages are often conflicting and where topics increasingly cut across a range of social, ethical and moral issues...........As responsible citizens they will need to be able to evaluate the benefits and risks associated with developments in science and their applications."*
>
> (SEED, 1999, page 2)

The whole area of scientific thinking is complex. It is possible for scientists to argue that their way of thinking is in some way superior while those outside the science areas may resent such suggestions, arguing that there is nothing unusual about scientific thinking. Indeed, the problem is that there is frequently complete uncertainty about what constitutes scientific thinking and different people may hold very diverse conceptions. Some curricula (eg Standard Grade Arrangements, 2006, page 6) seem to suggest that taking a course in a science discipline at school level will encourage the development of certain types of thinking. However, it is more likely that those who choose to take the course are those who tend to think that way anyway. This chapter is an attempt to unravel some of the key strands in the literature and to offer a clearer picture of what is meant by scientific thinking.

Before looking at scientific thinking, the whole world of thinking will be explored briefly, followed by a discussion of what is known about critical thinking, often confused with scientific thinking. Two other phrases occur widely in the literature: the scientific method and scientific attitudes. Both will be discussed in relation to scientific thinking. The aim in all this is to establish the key features of scientific thinking which make it different from other thinking.

7.2 The Nature of Thinking

Bruner (1986) clearly thought highly of scientific thinking but sees both the sciences and the humanities as contributing to the development of understanding, speaking of systems of logic which make sense of the world around. Dewey (1998, p.viii) describes, '*reflective thinking: the kind of thinking that consists in turning a subject over in the mind and giving it serious and consecutive consideration.*'. He sees the objective of thinking as seeking meaning; while the object of knowing is to establish truth. Of course, this implies that there is a truth to be known. Dunbar *et al*., (2001) emphasise the expertise needed in developing thinking skills. This suggests that the place of formal teaching as well as life experience may be vital.

Dewey (1998, pages 107-114) goes on to describe reflective thought in terms of five phases:

> '(1) *Suggestion*: This explores purpose and its conditions, resources, difficulties and obstacles.'
>
> '(2) *Intellectualisation*: The conversion of a perplexity into a problem to be solved, a question for which the answer must be sought.'
>
> '(3) *The Guiding Idea*: This involves the idea that one idea can lead to another; indeed, the ideas can guide future observations and data gathering.'
>
> '(4) *Reasoning*: The mental elaboration of the idea or development of an idea or supposition (reasoning, in the sense in which reasoning is a part, not the whole, of inference).'
>
> '(5) *Testing the Hypothesis by Action*: Testing the idea or hypothesis by overt or imaginative action. The concluding phase is some kind of testing by express action to give experimental corroboration, or verification, of the conjectural idea.'

Kong (2006) debates the balance between the emphasis on rote learning and thinking skills in modern education, especially in the light of the massive information and technology explosion. He argues that there is an urgent need for school pupils to learn thinking skills, with memorisation no longer holding the key place. This follows Bruner's (1996) emphasis on 'thinking about thinking' to be seen as a principal ingredient of any empowering practice of education. There may be encouraging signs as Fisher (1995) notes the increasing emphasis on interpretation subjects like drama and literature, moving on into history and the social sciences. This has happened in subject disciplines but is now moving on into education where understanding, interpreting, reflecting are all more highly valued. Patrick *et al.,* (2003) argue that even young children should be introduced to what they call 'philosophical thinking' while Fisher and Hicks (1985) suggest that some key goals in education have to be '*learning to learn, solving problems, clarifying values and making decisions*'.

Looking specifically in the area of the sciences, Schafersman (1994) notes that they are not merely a collection of facts, concepts, and useful ideas about nature although it has to be noted that a science discipline is often defined in terms of its body of facts or its contribution to understanding the world around. His focus is on science as a *method* of discovering reliable knowledge about nature. This is not unrelated to Tweney's (1981) idea that scientific discovery is a form of problem solving. Indeed, the processes whereby science is carried on can be explained in the terms that have been used to explain the processes of problem solving (Reigosa *et al.*, 2001; Duschl, 1990). Science is not just the relationships between laws and observations: scientific theories themselves should be seen as research programmes and the students should be given activities that allow them to exercise appropriate argumentative skills (Driver *et al.*, 2000).

Johnstone *et al.,* (1992) argue that schools need to produce students capable of higher-level thinking skills, communication skills, and social skills. Zohar *et al.,* (2003) argue that teachers should encourage students of all academic levels to engage in tasks that involve higher order thinking skills. This illustrates some of the problem. What are these higher order thinking skills? How do they relate to scientific thinking? Can these skills be developed by formal education?

Zohar *et al*., (2003) assert that most schools do not teach their students to think and read critically or to solve complex problems. Textbooks tend to be full of information to be memorised and most tests assess students' ability to remember these facts. This leaves the main role of teachers as that of transmitting information to students. Sadly, this picture is often very accurate. However, such a negative picture raises some real issues. Are the thinking skills which might be described as 'higher order' or 'scientific' *accessibl*e at school level, or 'psychologically realistic'. (Nerswssian, 1992).

Bruner (1972, page 60) argues that there is nothing more central to any discipline than its way of thinking. Indeed, there is nothing more important in its teaching than to provide the child with the earliest opportunity to learn that way of thinking. He wants the young learner to think, to be given the chance to solve problems, to conjecture, even to disagree and argue. This raises several issues: from where can the time be found? Are teachers equipped to manage such learning? Can such learning opportunities be structured in ways which facilitate effective learning? Reid (1991) notes that it is possible that each science discipline has a major place in introducing the '*way of knowing*' that is science. The unique contribution of the sciences in the curriculum may be to develop the skills so that the learner can address questions of the physical world in such a way that meaningful answers can be obtained.

Gold (2002) has argued that research evidence shows the value of teaching children to think. He quotes the evidence from the Cognitive Acceleration in Science Education programme where 4,500 pupils across England improved their national test scores and GCSE results (national examination in England sat at about age 16) considerably after 30 hours teaching of thinking skills during year 7 science (around age 13). However, it is possible to interpret these findings in terms of how these thinking activities develop 'chunking skills' (see Miller, 1953) which free working memory to help achieve greater levels of understanding.

All cognitive processes are internal and they are important to the extent that they affect the way a person does things. Thus, Norris (1985) notes that students need more than the ability to be better observers; they must know how to apply everything they already know and feel, to evaluate their own thinking, and, especially, to change their behaviour as a result of thinking critically. Paul (2003, page 2) goes further when he states that, "*The quality of our life and that of what we produce, make, or build depends precisely on the quality of our thought. Shoddy thinking is costly, both in money and in quality of life. Excellence in thought, however, must be systematically cultivated.*"

Fisher (1995, page 1) observes

> *"These processes of perception, memory, concept formation, language and symbolisation as the basic cognitive skills that underlie the ability to reason, to learn and to solve problems. To study thinking is to study these structures and processes through which we as humans experience and make sense of the world.*"

This picture emphasises the internal nature of the process while showing that such processes are important in making sense of the world around. They are gained by means of formal learning and experience (Nisbet, 1993). Nickerson (1985) describes possible teaching approaches while Gagne (1967) and Klausmeier (1980) suggest focussing instruction on eight basic processes of science: observing, using space-time relationships, using numbers, measuring, classifying, communicating, predicting, and inferring. In all of this, there is much good advice but a lack of clear evidence about what can be achieved.

Resnick (1985, page 15) seems to suggest that such thinking skills are essentially generic when he notes that,

> *"Certain kinds of higher-order thinking may be seen in the performance of highly skilled individuals whether they are doing mathematics, reading, solving scientific problems, composing essays, or repairing equipment: Experts elaborate and reconstruct problems into new forms; they look for consistencies and inconsistencies in proposed solutions; they pursue implications of initial ideas and make modifications rather than seeking quick solutions and sticking with initial ideas; they reason by analogy to other similar situations."*

Nickerson (1985) states that there appears to be an increasing awareness among advocates for the teaching of thinking of the critical importance of attitudinal and dispositional variables as determinants of the quality of thought (Baron, 1985; Ennis, 1985, 1987; Fraser and West, 1961; Hudgins, 1972; Newmann, 1985; Nickerson, 1986; Resnick, 1987; Schrag, 1987; Swartz, 1987). Among the attitudes mentioned are fair-mindedness and openness to evidence on any issue; respect for opinions that differ from one's own; inquisitiveness and a desire to be informed; a tendency to reflect acting. Some investigators (Newmann, 1985; Schrag, 1987) have argued that the cultivation of thoughtfulness is a more important objective for education than the development of specific thinking skills. However, students need to feel free to question, to explore, to expose knowledge limitations or misconceptions without fear of ridicule.

In the area of thinking skills, inductive thinking and deductive thinking are sometimes mentioned. Marten (1997) describes induction as '*the principle of reasoning to a conclusion about all the members of a class from examination of only a few members of the class; broadly, reasoning from the particular to the general.*'. However, he redefines an inductive argument as an argument in which the premises give us good reason to believe the conclusion. He also emphasises that modern logicians tend to look at reasoning from general to the particular.

Marten (1997) notes that deductive reasoning can be seen as deducing the particular from the general principle. He considers deductive reasoning as superior to inductive. However, induction is the central feature of scientific reasoning. Nonetheless, an acceptable inductive argument with true premises may give a false conclusion. He argues that science uses inductive reasoning all the time because the corresponding deductive argument would require information that is unavailable or too costly and thus not worth it to obtain.

There is general agreement that the development of thinking should have an increased place in education at all levels, memorisation and recall being de-emphasised. However, there is a very wide range of views of what constitutes the essential nature of such thinking and there is little consensus about how such skills might be enhanced or, indeed, measured. The area of critical thinking is now considered to see whether there is any clearer picture.

7.3 Critical Thinking

> *'Students need more than the ability to be better observers; they must know how to apply everything they already know and feel, to evaluate their own thinking, and, especially, to change their behaviour as a result of thinking critically.'*
>
> Norris (1985, page 40

Many have argued for the importance of critical thinking as an essential goal for education (eg. Norris, 1985; McPeck, 1981; Siegel, 1980, 1984). Fisher and Scriven (1997) define critical thinking as the skilled, active interpretation and evaluation of observations, communications, information and argumentation. Critical thinking is reasonable, reflective, responsible, and skilful thinking that is focused on deciding what to believe or do. Norris (1985, page 44) argued that '*critical thinking is an educational ideal, it is not an educational option and students have a moral right to be taught how to think critically.*'

Zeidler *et al.,* (1992) consider that the concept of critical thinking is sometimes generically used as an umbrella term to include all thinking operations, or sometimes equated with "problem solving" or the higher levels of Bloom's taxonomy (Bloom and Krathwohl, 1956). However, Beyer (1988) agrees that critical thinking requires a certain mind-set that is essentially evaluative in nature, but distinguishes critical thinking from "micro thinking skills" such as Bloom's taxonomy and those typically taught in logic and philosophy (inductive, deductive, and analogical reasoning). Beyer also differentiates critical thinking from "thinking strategies" such as problem solving and decision making which are more complex cognitive processes aimed at the process of developing support to formulate a particular model or solution from what was initially a problematic situation or dilemma. Such thinking strategies consist of following a hierarchical sequence of subordinate procedures.

Gabennesch (2006) conceptualises critical thinking in terms of three essential dimensions:

Skills: Critical thinking involves the various higher-order cognitive operations involved in processing information, rather than simply absorbing it: analysing, synthesising, interpreting, explaining, evaluating, generalising, abstracting, illustrating, applying, comparing, recognising logical fallacies.

Worldview: '*The recognition that the world is often not what it seems is perhaps the key feature of the critical thinker's worldview.*'

Values: The critical thinker is committed to the concept of the intellectual process as the best way to increase the likelihood of finding the truth.

However, Gabennesch (2006) indicates that the skills dimension is what most people appear to have in mind when speaking of critical thinking while Bailin (2002) indicates that much educational literature equates critical thinking with certain mental processes or procedural moves which can be improved through practice. This is parallel to scientific thinking when it is seen in terms of a procedure: for example, that proposed by Friedler *et al*., (1990, page 364) involving, 'defining the problem; stating a hypothesis, designing an experiment; observing, collecting, analysing and interpreting data; applying the results; and making predictions based on the results.' The practice elements are implied by Tobias (1993) who suggests that, "*if creative, innovative students are to be retained in greater number, they need to have the opportunity to think critically about what they are learning rather than just go through repetitive skills and knowledge acquisition.*"

Schafersman (1994) emphasises that critical thinking is most likely to lead to the most reliable answers while Dewey (1909, page 9, cited in Fisher (2001) described it as: "*Active persistent and careful consideration of belief or supposed form of knowledge in the light of the grounds which support it and the further conclusions to which it tends*". Fisher (2001) draws both ideas together when he emphasises both the use of reason and the idea of reflective thinking. Fisher and Scriven (2002, page 20) describe critical thinking as "skilled and active interpretation and evaluation of observations and communications, information and argumentation." Their emphasis is on 'active' because both questioning and metacognition may be involved. In addition, Moore (2004) argues that by critical thinking offers a way of reaching definitive and final judgements about the rightness and wrongness of propositions, about the correctness and incorrectness of solutions, and about the validity of ideas.

Zoller (2000) focusses on higher-order cognitive skills (Zoller, 1993; Zoller and Tsaparlis, 1997). Such skills include, among others, the ability to ask questions, solve problems, make decisions, and critical thinking (Ennis, 1989; Paul, 1992; Perkins *et al*., 1993). Descriptions like rational, logical, reflective, and evaluative thinking and purposeful, inquiry oriented, consistent interpretation of the relevant in formation, based on sound and reasonable inferences leading to conclusions are used (Facione, 1990; Zoller, 2000).

Both Fisher (2001) and Schafersman (1994) offer a list of the skills involved in critical thinking. While their lists are not identical, there are some general common features:

(1) Recognising problems or asking the right questions;
(2) Gathering information;
(3) Interpreting what is given;
(4) Recognising unstated assumptions and values;
(5) Reasoning logically from this information;
(6) Drawing warranted conclusions and generalisations;
(7) Putting to test the generalisation and conclusions reached.

Halpern (1998, page 351) also suggests a range of skills not too dissimilar to the above while Ennis (2001) goes on to suggest that the ideal critical thinker is seeking not only to try to '*to get thing right*' but also to care about the worth and dignity of every person. In his list of seven characteristics of an ideal critical thinker, Kong (2007, page 5) includes phrases like '*habitually inquisitive, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgement, willing to reconsider*', these suggesting more than simple cognitive skills. They have attitudinal overtones.

Fisher (2001, page 164) indicate that Ballard and Clanchy (1995), for example, argue that although a generic skill like critical thinking can only be developed within specific contexts of knowledge, once learned '*it does not have to be learned totally anew in each new context of knowledge*'. This raises the question: is critical thinking a generic skill or is it context related?

Schafersman (1994) argues that critical thinking is perhaps the most important skill a student can learn in school and college since it offers to the student a way to think successfully and reach reliable conclusions. Marten (1997) considers that critical thinking is seeking to ask the "why" question. The "what", "when", or "which" questions do not seek for explanations.

McPeck (1990) draws out key points when he states that there are two key issues: what critical thinking is exactly, and how is it best taught. He notes that the answer to the first will influence the answer to the second. Gibbs (1985) note four studies of measures of critical thinking which show that critical thinking can be effectively taught at the university level. However, this does not offer any insights into what is possible at school.

Like the analysis of thinking skills, there are widespread views about the nature of critical thinking. Nonetheless, there is considerable measure of agreement and this is summarised in table 7.1.

	Critical Thinking: Summary of Research
1	Critical thinking is a complex of many considerations. It requires individuals to assess their own and others' views, to seek alternatives, to make inferences, and to have the the disposition to think critically.
2	Critical thinking is an educational ideal. It is not an educational option. Students have a moral right to be taught how to think critically.
3	Critical thinking ability is not widespread. Most students do not score well on tests that measure ability to recognise assumption, evaluate arguments, and appraise inference.
4	Critical thinking is sensitive to context. Students' background knowledge and assumptions can strongly affect their ability to make correct inferences Inferences are more likely to be correct when the context relates to the individual's personal experience and when performance is not associated with threats or promises.
5	Teachers should look for the reasoning behind students' conclusions. Coming up with correct answer may not be the result of critical thinking.
6	Simple errors may signal errors in thinking at a deeper level. In trying to solve complex problems, for example, students may make error not just by making a miscalculation but by using an incorrect approach to the problem. They should be encouraged to take time before solving a problem to decide how to go about finding the
7	Having a critical spirit is as important as thinking critically. The critical spirit requires one to think critically about all aspects of life, to think critically about one's own thinking, when using critical thinking skills.
8	To think critically, one must have knowledge. Critical thinking cannot occur in a vacuum; it requires individuals to apply what they know about the subject matter as well as their common sense and experience.

Table 7.1 Critical Thinking (Source: Norris, 1985, page 44)

7.4 Scientific Thinking

If scientific thinking describes the way scientists think, then the problem is that there seems to be no clear precise definition of scientific thinking which fits all situations. For example, it is possible to consider the three cases:

(1) Kepler (1959) was trying to get evidence for his idea: platonic solids model. Accidentally he discovered the correct laws of planetary motion. However, he did understand that he needed the best possible observations to work with.

(2) Darwin (1887) did not seem to have the right to make a great discovery. Interested in lots of things, he made many observation, collected many specimens. Only after 20 years of reading, writing, collecting did the idea of evolution through natural selection occur to him. Even then, he was rather afraid of what others would say.

(3) In 1906 when he was 25, Einstein noted that the way in which you treat the case of a magnet moving near a stationary conductor is quite different from the case of a stationary magnet and a moving conductor, yet the result (the current in the conductor) is the same and depends only on the relative motion. This is something that hundreds of people must have noticed, but none of them drew the right conclusion.

This illustrates the problem. The areas where scientists have worked are very diverse. Of greater significance is the fact that personal characteristics and ways of working vary enormously among scientists. The supposedly cold logical ways of thought are often absent! However, Zimmerman (2007, page 172) suggests that developmental psychologists have been interested in scientific thinking because it is a fruitful area for studying conceptual formation and change and the development of reasoning and problem solving skills.

Scientific thinking is defined as the application of the methods or principles of scientific thinking inquiry to reasoning or problem-solving situations, and involves the skills implicated in '*generating, testing and revising theories*', and in the case of fully developed skills, to reflect on the process of knowledge acquisition and change (Koslowski, 1996; Kuhn and Franklin, 2006; Wilkening and Sodian, 2005). The phrase, 'generating, testing and revising theories' seems particularly important.

Stuessy (1984) in Hong-Kwen and Kok-Aun (1998) has the same idea when he notes that scientific thinking is the logical and consistent thought patterns which are used by individuals in formulating and testing hypotheses during the process of scientific inquiry. Kuhn *et al.,* (1988) argue that at the heart of scientific thinking is the skilful coordination of theory and evidence.

There are many other definitions which have been proposed (Frederiksen and William, 1978; Klahr, 1994; Dunbar, 1997; Dewey, 1998; Paul and Elder, 2003) but the ideas proposed often do not seem to separate scientific thinking from other forms of thinking. There is often a confusion between scientific thinking and critical thinking (see Schafersman, 1994). Sometimes the two are seen as essentially the same but critical thinking becomes scientific thinking when practised by scientists! Nonetheless, many descriptions refer to questions, observations, data, hypotheses, testing, and theories.

Schafersman (1994, page 3) states that most aspects of scientific thinking revolve around three things:

(1) *Empiricism*: the use of empirical evidence;
(2) *Rationalism*: logic allows us to reason correctly;
(3) *Scepticism*: constantly examining the evidence, arguments, and reasons for their beliefs and conclusions.

Dewey (1909, page 247, cited in Fisher and Scriven (2002) saw scientific thinking as a model of "reflective thinking" and offers a list of seven skills, summarised below:

- *Identify the element in a reasoned case, especially reasons and conclusion.*
- *Identify and evaluate assumption;*
- *Judge the acceptability, especially the credibility, of claims;*
- *Evaluate arguments of different kinds;*
- *Analyse, evaluate and produce explanation;*
- *Analyse, evaluate and make decision.*

Dierking and Falk (2001) discuss studies which have sought to describe how individual children form hypotheses, collect evidence, make inferences, and revise theories. The process of scientific thinking has been described as depending on the coordinated search of at least two problem spaces: a space of evidence and a space of theories (Klahr & Dunbar, 1988).

Martin (1997) considers that scientific thinking is admirably clear and linear. It takes the student from the elementary position of undirected observation through problems in sampling to issues in explanation, causation and classification. However, this seems to be a great over-simplification.

Schafersman (1994) makes the amazing statement that all scientists practice scientific thinking when they are actively studying nature and investigating the universe by using scientific method. He does go on to admit that any one can "*think like a scientist*" when one uses the methods and principles of scientific thinking in everyday life. Any close look at any group of scientists would challenge the former while the latter admission seems to reduce scientific thinking to any kind of thinking.

Dunbar (1988) indicates that many researchers have regarded hypothesis testing as a core attribute of scientific thinking. Much of this work is based on Karl Popper's idea that the best way to test a hypothesis is to attempt to disconfirm the hypothesis. However, it is often found that subjects try to confirm their hypotheses rather than disconfirm their hypotheses. Nonetheless, many researchers have regarded hypothesis testing as a core attribute of scientific thinking. In this regard, Bruner (1972) noted that his students enjoyed discussing not only whether the hypotheses were 'true' but also whether they were testable.

This approach requires some kind of definition of an hypothesis. Hoover (1984) argued that hypothesis formation has an organisational purpose and can offer some kind of structure for what is observed. Indeed, an hypothesis can sometimes suggest some kind of relationship between two or more variables and can be seen as the starting point for further investigation where it can be proved or disproved.

Hypotheses are unfit when they are out of accord with reality or when they fail to illuminate existing knowledge or suggest worthwhile new facts, experiments, observations or points of view (Piaget (1977). Bruner (1986) holds a very positive view about the formation of hypotheses, seeing these as not just the province of the sciences and very important in many areas of life.

Park (2006) states the most widely used definition of hypothesis in science education is to view scientific hypothesis as the '*tentative causal explanation regarding an observed effect*' (see Wenham, 1993). Quinn and George (1975) defined a hypothesis as a testable explanation of an empirical relationship among variables in a given problem situation, while Fisher *et al*., (1983) argue that hypothesis generation is the process of creating possible, alternative explanations for a given set of information.

Stephen *and* Sue Dale (2001) assert that school pupils not only notice, from their own undirected observations, important features but that sustained observations may provide a base for clearer hypothesis-making when formal teaching and investigations begin. This view may be somewhat optimistic. For example, Zohar *et al.,* (2003) found that higher order thinking skills (of which hypothesis formation might be one) tended to be seen more with high ability school pupils.

In studying scientific thinking, the inevitable tendency has been to take one aspect of the thinking process and look at it critically (Dunbar, 1988). Scientific thinking is probably more than the collation of a number of specific skills. However, the investigation of the whole process is, by its very nature, very difficult to undertake.

Nonetheless, Tweney *et al*., (1981, page 407) propose three laws of scientific thought:

> *"(1) Every hypothesis continues in a state of belief unless acted upon by a force. This follows from the empirical work on confirmation and disconfirmation.*
> *(2) The degree of belief in a particular hypothesis is directly proportional to the similarity between the hypothesis prediction and the empirical facts.*
> *(3) For every hypothesis there is at least one alternate hypothesis. In most cases, this will be provided by the social context."*

Students need to understand that scientific theories and conclusions are human constructs. As a result, students should learn to challenge alternative explanations for the same phenomenon by addressing weaknesses in other possible explanations or frameworks as a part of their argument. Kenneth and Donovan (2007) relate scientific thinking skills to the strategies which can be used to cope with life, especially the uncertainty of life. They see this kind of thinking in terms of what they call 'reality testing': taking ideas and confronting them with evidence.

Schafersman (1994) have offered an analysis of scientific thinking (figure 7.1) below.

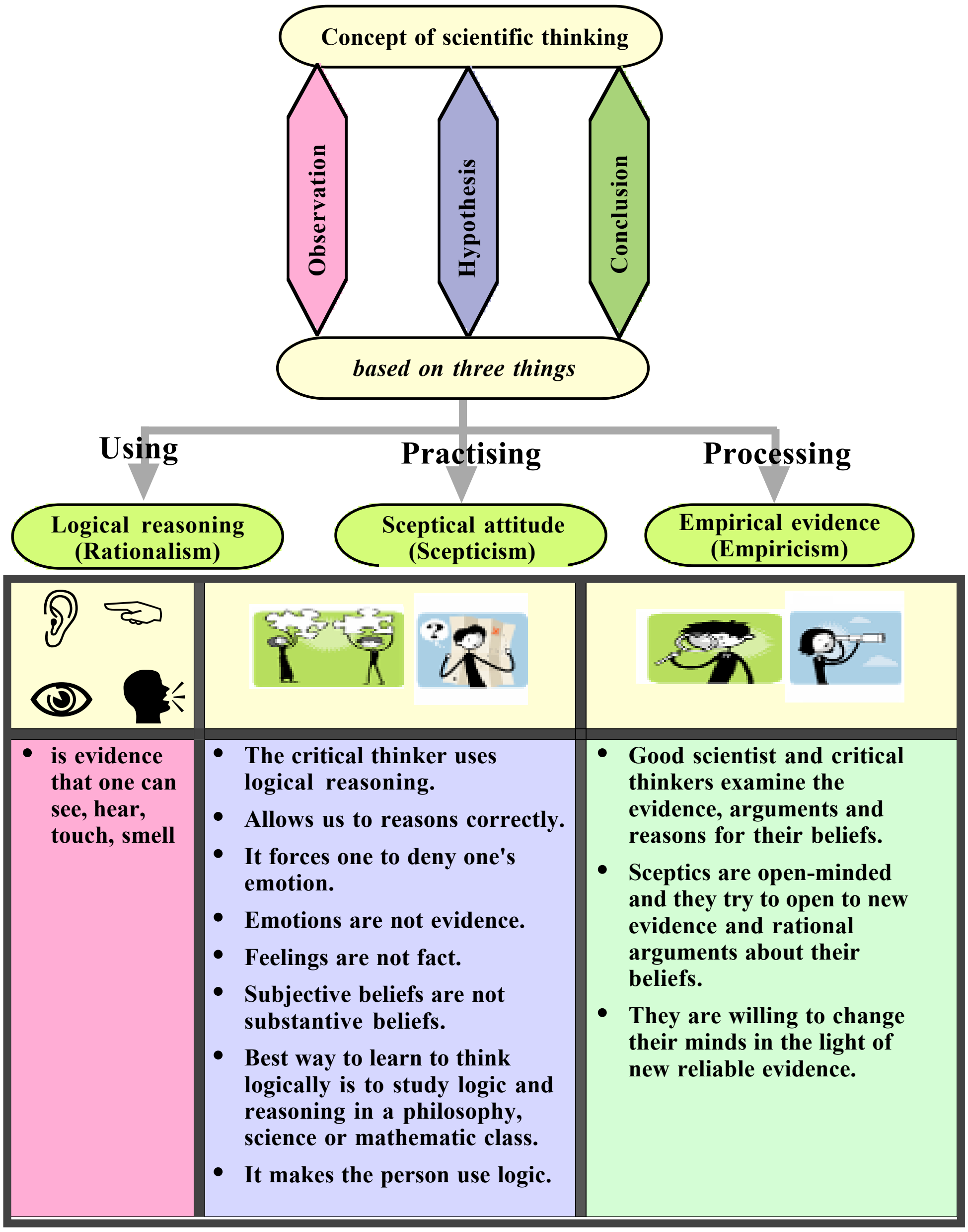


Figure 7.1 Concept of Scientific Thinking (derived from: Schafersman, 1994)

While logical thinking and sceptical attitudes are almost certainly very generic skills and not specific to scientific thinking, the place of empiricism is very much the province of the scientist.

Lochhead and Clement (1980) describe that the elements of what they call the scientific strategy (figure 7.2)

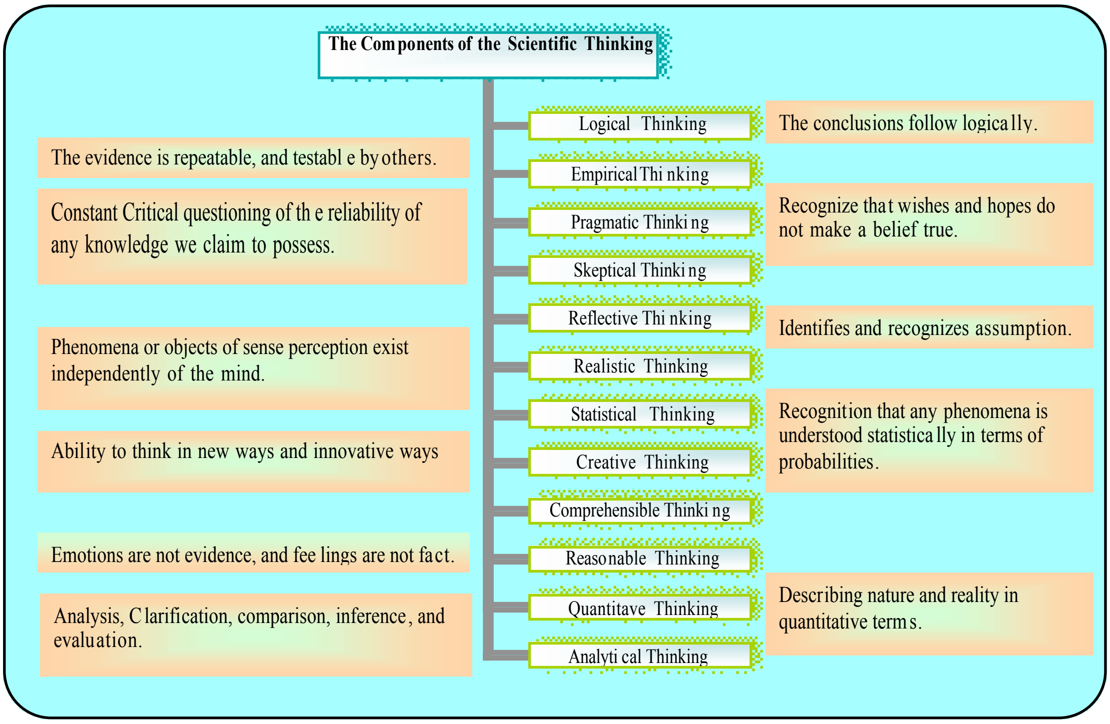


Figure 7.2 Scientific Strategy (derived from Lochhead and Clement, 1979)

This offers a comprehensive approach and the authors have tried to cover all aspects. However, this means that much is wider than scientific thinking and indeed, might be claimed by students in many other non-science disciplines.

Intellectual Standards in Scientific Thinking

Clarity	Ability to elaborate further hypotheses (or ideas)
Accuracy	How to check on data? How to verify or test that theory?
Precision	Ability to be more specific? Ability to give more details on the phenomenon? Ability to be more exact as to how the mechanism takes place?
Relevance	How do data relate to the problem? How do they bear on the question?
Depth	What factors make this a difficult scientific problem? What are some of the complexities we must consider?
Breadth	Do need to look at this from another perspective? Do need to consider another point of view? Do need to look at this in other ways?
Significance	Are all the data consistent with each other? Are these two theories consistent? Is this implied by the data we have?
Logic	Is this the central idea to focus on? Which set of data is most important?
Fairness	Do you have a vested interest in this issue which keeps you from looking at it objectively? Are you misrepresenting a view with which you disagree?

Figure 7.3 Intellectual Standards in Scientific Thinking
(Source: Paul and Elder, 2003, page 13)

Again, the authors have tried to cover as many aspects as possible and have included many skills that are not unique to scientists. This is the real danger in such analyses. The key is to focus in what is unique to scientific thinking which makes it different in some way from other levels of advanced thought.

Buchdahl (1993) offers the most complex analysis (figure 7.4) of scientific thinking.

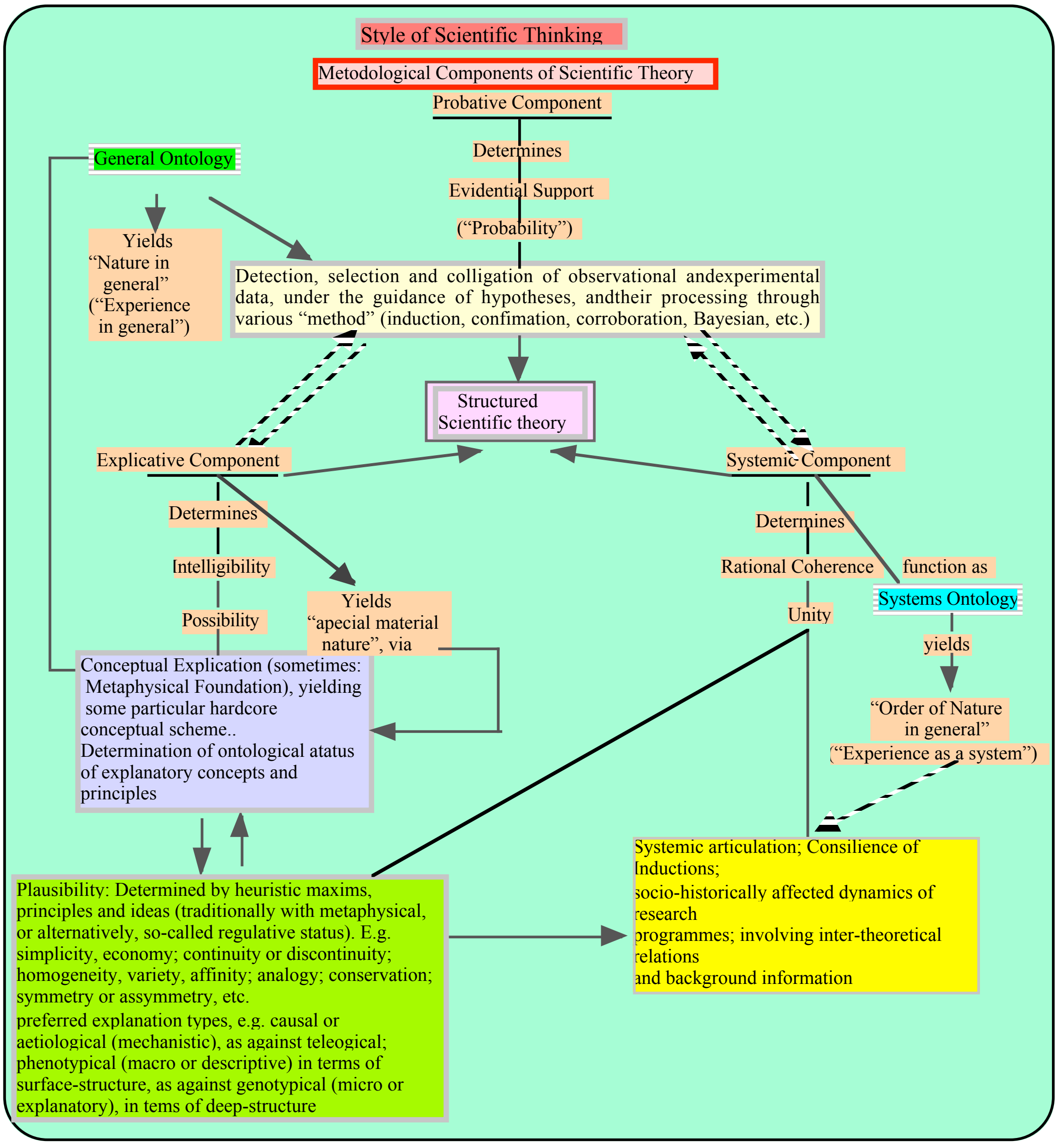


Figure 7.4 Styles of Scientific Thinking (source: Buchdahl, 1993, page 159)

The problem with all such analyses is that, in their attempt to capture every situation, their complexity makes them inaccessible for the reader. Perhaps the key feature of scientific thinking is the focus on the empirical as a means by which hypotheses can be tested.

7.5 Thinking Like a Scientist

> *"Have you ever wondered what goes on inside scientists' heads when they formulate a grand theory? Or when they decide what hypothesis to test? How does this differ from the mundane reasoning involved when you explain why your car won't start or choose a birthday present for a relative? More generally, do scientists use the same cognitive mechanisms available to us all (supplemented with formal, conceptual, and technological tools)? Or does scientific thinking require more specialised cognitive abilities, available to only a talented few?"*
>
> Lagnado (2006)

Even concepts considered of great importance by scientists of one era may become of no importance at all later and yet not be in any sense wrong. An example is the famous equation of Einstein: $E = mc^2$. First appearing in 1908 as a consequence of Einstein theory of Special Relativity, this equation may eventually vanish from the textbooks. To understand why it is helpful to consider a similar situation from the past.

Before the work of Joule, it was not known that heat was a form of energy. The energy unit was the calorie and this was defined as the amount of heat energy required to raise the temperature of one gram of water by one degree Celsius. Joule demonstrated that mechanical energy can be converted to heat energy. Joule found that the relationship between the energy expended as a propeller turns was directly correlated with the rise in temperature, with a constant of proportionality equal to 4.186 J/Kg/C^0. This then defined the calorie as 4.186 J. Then the Joule replaced the calorie and the constant became unity: E = H.

Looking at $E = mc^2$: this relationship made its full impact with the first atomic bomb in 1945. The idea grew that body mass can be seen as increased speed. In the same way,when mass and energy are conventionally measured in the same units $E = mc^2$ will disappear.

Marten (1997) suggested that most people walk around in the world not really noticing things, but they start to be scientists when they learn how to observe things carefully. He emphasised the importance of careful observation but also stressed that scientists need to clear their minds of every preconception and prejudice: "*Because science is the search for truth, real scientists should be open-minded or perhaps empty-minded is a better term*" (Marten, 1997, page 8). Such a view is hardly realistic. Humans are probably incapable of being totally objective in any way. It is more or less impossible to remove from the mind years of experience or even the situation of the last experiment.

Dunbar (2000, 1997) describes the scientists as they are constantly adding to knowledge and, less frequently, developing new concepts and theories. He appreciated the rich background of knowledge needed as a foundation for their thought but also noted the importance of creativity which occurs in group activity rather than solitary work (see Klahr, 1994; Tweney *et al*., 1981). This group activity is a strong feature of much scientific work.

Dunbar (1995, 2000) specified some types of thinking and reasoning strategies they use in generating a new concept, modifying an old concept or solving difficult problems:

> *"(a) Scientists focus on unexpected findings as a source of new experiments and theories, and they make extensive use of negative evidence to discard their hypotheses.*
> *(b) Analogic experiments, and interpreting data. However, the use of local analogies where knowledge is imported from the same scientific domain is a common mechanism of conceptual change.*
> *(c) Scientists frequently engage in distributed reasoning when they encounter a problem in their research."*
>
> Dunbar (2000, page 52)

Hyde (1970) asserts that the scientist is always seeking to find law and order in the world around him: patterns which account for observations. From these observations, the attempt is made to develop hypotheses which are tested and retested, varying both the method and content of his experiments.

Schafersman (1994) implied that anyone can think 'like a scientist': all that was required was to learn the scientific method. This view makes several assumptions. It assumes that all are capable of learning this method and that there is a method to be learned. However, it does raise the important question about how scientific thinking might be approached in teaching and learning. Hoover (1984) offered a possible way forward which is summarised below:

(1) Using the 'black box' idea to draw conclusions based on evidence.
(2) Using problem-solving methods and allowing students freedom.
(3) Working in collaborative groups in class activities.
(4) Introducing the idea of the variable.
(5) Teaching the students how to develop hypotheses.
(5) Gathering data and planning experiments.
(6) Analysing data.
(7) Writing down conclusions.

However, this series of recommendations assumes that the learners are capable of learning this way. Is learning in a science the same as being a scientist? This must be in serious doubt.

Kuhn (1989, 2002) has argued that the defining feature of scientific thinking is the set of skills involved in differentiating and coordinating theory and evidence. Most studies of students' ability to coordinate theory and evidence focus on what is best described as inductive causal inference (given a pattern of evidence, what inferences can be drawn?). However, children had some difficulties with first-hand observations (rather than researcher-supplied evidence). When children were capable of making the correct observations (which could be facilitated with instructional interventions), conceptual change was promoted (Chinn and Malhotra, 2002). An effective way of promoting children's observational abilities was to explain what scientists expected to observe and why. Similarly, a general '*anticipatory scheme*' may be effective (Kuhn and Ho, 1980) at the observational or encoding stage of evidence evaluation.

However, Chinn and Brewer's (2001) hypothesis that individuals construct a cognitive model in which theory and evidence are '*intertwined in complex ways*' (p. 331) is reminiscent of Kuhn's interpretation that students seem to merge theory and evidence into one representation of "how things are." For example, Kuhn (2002, page 192) has argued that the development of proficient scientific thinking involves the process of theory-evidence coordination becoming more explicit, reflective and intentional.

Zohar *et al.,* (2003) note that most of the classical scientific inquiry skills such as formulating hypotheses, planning experiments or drawing conclusions are also classified as higher order thinking skills, according to the Bloom taxonomy (Bloom and Krathwohl, 1956). Inhelder and Piaget (1958) demonstrated that children of different ages have different abilities in testing hypotheses and interpreted their results in terms of Piaget's stage theory. The real issue is that the way scientists tend to think is not necessarily accessible at younger ages.

Koponen and Mantyla (2006) assert that, in physics teaching, the conducting of experiments is absolutely central. In addition, experiments have such a central role in physics education that textbooks emphasise experiments strongly. They also note that the verification role of experiments is the preferred physicists' stance, expressed by Feynman *et al*., (1963) mentioning: "*The test of all knowledge is experiment. Experiment is the sole judge of scientific truth*". Physicists often mention experiments in the role of 'supporting' theory (Einstein 1970). The real problem is that, in much physics teaching, the 'facts of physics' are presented and the experiments are used to verify or illustrate them. In physics research, the role of the experimental is very different as it seeks to offer new insights or to test hypotheses. The experiment in research physics may not be seen in the same way when teaching physics.

7.6 Scientific Method

Another phrase widely used is the 'scientific method'. Schafersman (1994) describes the method as being used to justify scientific knowledge, and thus make it reliable. When a person uses the scientific method to study or investigate nature or the universe, one is practising scientific thinking. His analysis is presented in figure 7.5.

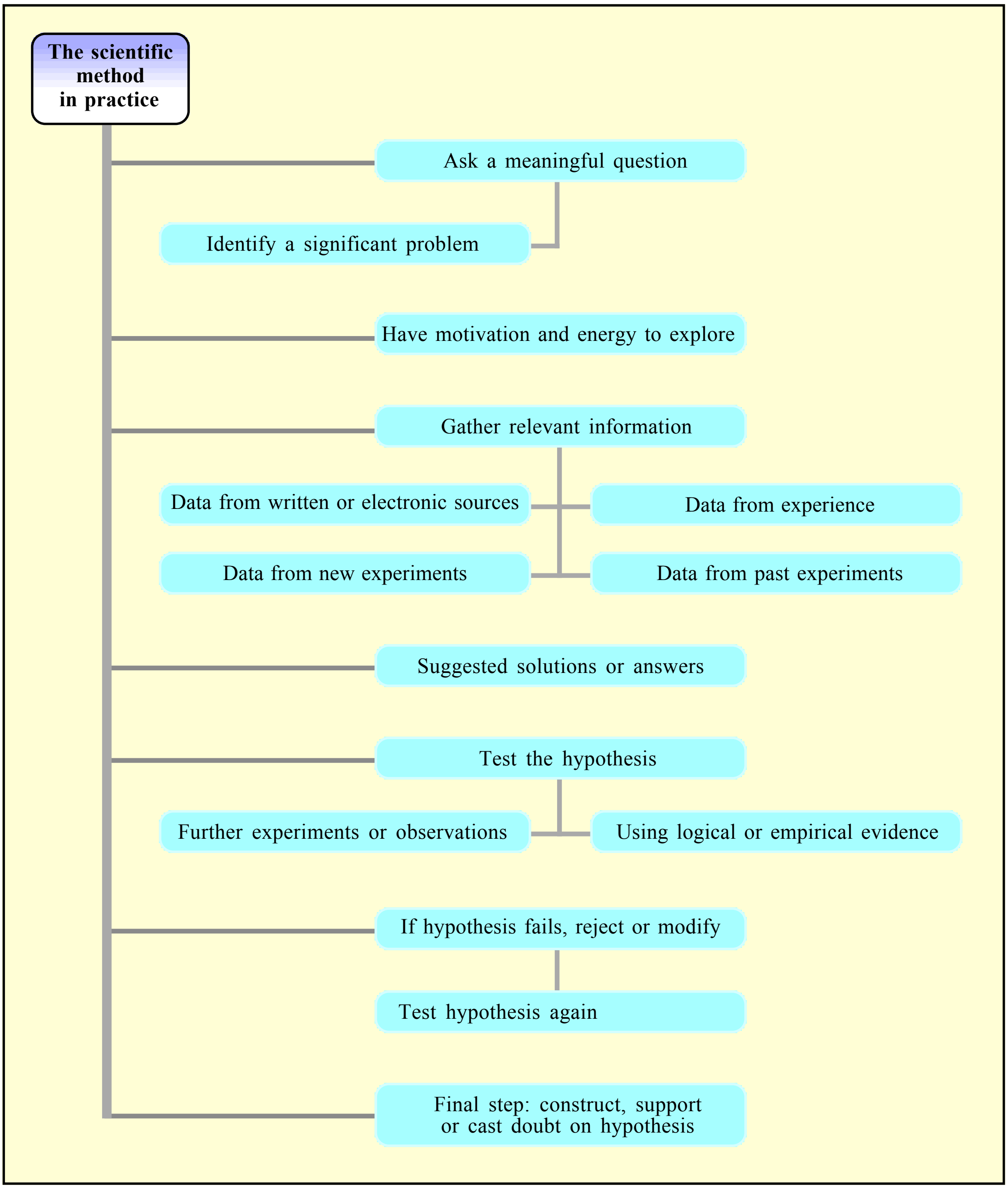


Figure 7.5 The Scientific Method (derived from Schafersman, 1994)

Schafersman (1994) reduces this to a simpler five step analysis which is summarised overleaf:

(1) State the problem or question in a way that an answer is possible, avoiding

emotion or bias;

(2) Gather relevant information to attempt to answer the questions or solve the problem by making observations;

(3) Develop an hypothesis or hypotheses, ensuring that these are as far as possible testable;

(4) Test the hypothesis by means of experiments;

(5) Accept, refine or reject the hypothesis in the light of the experiments.

It is easier to follow this analysis but it makes some assumptions. It leaves the impression that the scientist is able to be completely objective and to avoid personal involvement. This is much more difficult than implied here.

7.7 Scientific Attitude

Another phrase which occurs in many places is the 'scientific attitude'. This is now discussed briefly.

Many years ago, Baumel and Berger (1965) argue that scientific attitudes are among the most important outcomes which should result from science teaching. However, they emphasised that, if scientific attitudes are to develop from the study of science, they must be taught directly and systematically in the same manner as a mastery of the principles of science is developed. They defined such an attitude as looking for the natural causes of events, open-mindedness toward others and towards information related to his problem, basing opinions and conclusions on evidence, evaluating techniques, and curious about observations. Much is similar to the list from Reid (1978).

Baumel and Berger (1965, page 269) come up with a number of interesting suggestions, summarised below:

(1) Scientific attitude may be acquired by students at all levels of ability.

(2) The science teacher needs to evaluate not only the knowledge achievement of his students but also their growth in scientific attitudes.

(3) The student with scientific attitudes will more effectively cope with problems in school and community.

(4) Success in developing scientific attitudes depends ultimately on the teacher. The teacher must lead the students so that scientific attitudes are an integral part of their behaviour.

The first hypothesis is important in that it de-couples scientific attitudes from intellectual abilities but it makes a major assumption that such an attitude is accessible by all. The second hypothesis is also important in that, without giving value to this attitude, it will probably be neglected in teaching. However, how can it be tested? The fourth emphasises the vital importance of the teacher's role while the third is probably wishful thinking .

This third hypothesis is picked up by Grotzer and Zero (2007). They ask the fundamental question about whether this kind of attitude is generic: learned in a science room, can it be applied to the everyday events of life outside the classroom?. If it cannot be transferred (and there is little evidence in the literature to support transferability of such skills), they ask if it is worth learning. They argue that, if the attitude is to transfer, then three conditions must apply, which have been summarised and interpreted here:

(1) There needs to be a sensitivity or alertness for occasions to think this way;
(2) There needs to be the ability to think this way;
(3) The attitude needs to have value for the person.

Hare (1983, page 66) make an important point: "*We cannot, of course, infer from the fact that pupils emerge from school with closed minds that their teacher failed to teach in an open-minded way. There may be many forces at work in the homes of students, and in society at large, which make the open-minded attitudes of teachers ineffective*." However, for pupils to develop such attitudes, they must be practised by teachers and taught, explicitly or implicitly as an integral part of lessons in the science subject concerned (Kong, 2006).

Fender and Crowley (2007) found that research on children's scientific reasoning processes suggests the children have difficulty coordinating the systematic collection of evidence with the construction of appropriate theories (Kuhn, 1989; Kuhn, Amsel, and O'Loughlin, 1988).

Reid (1978) discussed areas connected to the teaching and learning of the sciences which might be considered as related to attitudes. In this, he outlined a model for scientific attitudes. However, he argues that the scientific attitude is not really an attitude but is more a way of thinking. In this, he is closer to describing the scientific method or scientific thinking. His analysis was based on five features:

(1) Directed Curiosity
(2) Logical Methodology
(3) Creative Ingenuity
(4) Objectivity
(5) Integrity

Reid (1978) refers to a variety of previous analyses of the scientific attitude (eg. Diederich, 1967; Haney, 1964). The advantage of his analysis is its simplicity and that it is easier to relate classroom and laboratory activities at school level to the descriptions. It is presented in full in table 7.2.

The Scientific Attitude - An Analysis		
1	Directed Curiosity	Desire to know - facts, principles, ideas; Desire to understand - mechanisms, functions; Desire to solve problem, and obtain "answers"; Desire to control - for some advantage.
2	Logical Methodology	A knowledge of, and a willingness to pursue, a logical and cyclical series of operations in satisfying directed curiosity; This series (entered any stage) is defined as: (a) Original hypothesis - recognised as an hypothesis; (b) Experimental approach to hypothesis testing; (c) The search for true relationships in experimental results; (d) The drawing of valid conclusions from results, in the light of previous work; (e) The relation to conclusions to original hypothesis, and hypothesis modification.
3	Creative Ingenuity	Willingness to build mental constructs or "models"; Willingness to set up realistic hypotheses; Willingness to design suitable experimental situations to test hypothesis; Willingness to see beyond set ideas in order to grasp or create new ideas.
4	Objectivity	Willingness to assess error, carrying out appropriate experimental replication, or statistical sampling; Desire for a level of quantification which is as precise as measurement allows; Willingness to control variables; Willingness to record results methodically; Willingness to view results in objective rather than emotional terms, avoiding premature claims; Willingness to distinguish description from explanation.
5	Integrity	Willingness to view initial problem without bias; Willingness to interpret results without imposing bias; Willingness to consider details that may appear contradictory; Willingness to consider implications of one's own work - health. and safety and possible misuse; Willingness to co-operate and communicate with others working in the same or allied fields; Willingness to respect instruments and materials.

Table 7.2 Scientific Attitudes (source: Reid, 1978, page 45)

The analysis above brings together much of the contributions of others. It is interesting to note that Reid did not generate this analysis simply by reviewing the literature of his day. The analysis was developed after consulting several practising scientists and applied scientists. He also talked to those involved in medical and mathematical research to see where their perspectives differed. The section on logical methodology corresponds largely to scientific thinking or scientific methodology. The observation that this cycle of events can be entered at several points is important. However, his caution about the word 'attitude' is probably correct - much is a way of thinking.

7.8 Possible Approaches to Teaching Scientific Thinking

> *"The teaching of thinking in this broad sense should be a fundamental, if not the fundamental, goal of education."*
>
> *Nickerson (1985)*

If scientific thinking is an important skill, then it is vital to consider how it might be developed in a school setting. There are two aspects to be considered. The first is to establish what can be developed at what ages. Piaget (1962) has described the developmental stages through which all learners progress and it is only after about the age of 12 that the cognitive skills start to develop to enable the learner to think in terms of an hypothesis as a way of considering and interpreting information. It is, therefore, unlikely that genuinely scientific thinking can be developed at too young an age although underpinning ideas and skills can perhaps be considered. The second aspect is to consider the teaching approaches which might be most likely to bring benefit. The literature is full of suggestions on ways by which scientific thinking can be developed at school level. There is great lack of any evidence to show that the suggestions do, in fact, work.

The study of Dierking and Falk (2001) stresses the importance of the developmental and that this aspect is often not considered fully enough when considering the role that parents may play guiding children. Womack (1988) note that most younger children are naturally curious. This offers a starting point when developing the ideas of how to understand the world around. He also argues that children should also be helped to see the connections between science and other school subjects, the connections within science itself and between the ideas and inventions of one scientist and those of another, although this will be at a simple level. He goes on to say that children should be given the opportunity to practise the processes of science-making hypotheses and considering the evidence for and against a particular idea. These arguments have little support in the literature. Young children cannot handle many of these abstract ideas, seeing things in the physical and descriptive sense. Indeed, the work of Johnstone *et al.,* (1997) shows very clearly that the reasoning chain of young children simply will not allow many of these recommendations to be fulfilled and, indeed, the idea of hypothesis formation is simply out of reach at these ages.

Thinking of older learners, Zohar *et al*., (2003) argue that students need to learn how to read popular scientific articles written by lay people in a critical manner and how to solve complex problems that involve science, technology and society in an effective way. Again, these are ideals but until the assessment procedures of most countries offer rewards for these types of skills, there is little chance of them finding much space in the learning experience of most young people.

Hoover (1984) is of the opinion that the best way to teach the students to think it is by showing them how to write things down in the way they occur in the mind: a sequence of ideas, thoughts. These can be used to frame their ideas into hypotheses and test them. Again, little evidence is offered to support such ideas. In the field of open-ended problem solving, it has been shown very clearly that students simply do not wish to (or cannot) write down plans (see Reid and Yang, 2002a; Bodner 1991). It is highly unlikely, therefore, that any written approach will bring much benefit.

Thornton (1987) argues that the computer can assist by displaying data in a manner that can be manipulated. This is seen as part of the laboratory, allowing the students to concentrate on the scientific ideas that are the goal of their investigation. This might avoid the 'cookbook' laboratory and the approach seeks to develop an inquiring approach to science. This has considerable potential and has similar features to certain aspects of pre- and post lab exercises used at university level (see Carnduff and Reid, 2003) which have proved so successful (Johnstone *et al*., 1993; Johnstone *et al*., 1998).

Gold (2002) argues that thinking skills should be taught across the curriculum and not as a separate subject, through classroom teacher-led activities like mind-mapping, followed by discussion and reflection among pupils. This approach seems to hold potential but, again, evidence is lacking.

McKendree *et al.,* (2007) makes the important point that there are generally three models for teaching thinking skills: embedded within a subject, subject-independent, and a mixed model where a set of generic attitudes and skills are applied to specific knowledge and experience across the curriculum. This raises the question about the extent to which scientific thinking is, in fact, a generic skill.

Bailin (2002) suggests that students should be involved in having them design an experiment to test a causal hypothesis which they have generated after making an observation. However, this assumes that the students are of sufficient age and experience to handle such ideas. Nonetheless, with older secondary school students, the approach holds considerable potential.

Many have argued for scientific thinking (using a variety of phrases and descriptions) simply because it makes studies in the sciences more attractive to learners or because such an approach appeals to the natural curiosity of learners (Tobias, 1993; Patrick *and* Costello, 2003; Dierking and Falk, 1994; Gelman *et al*., 1991; Zohar and Dori, 2003). Many of these stress the importance of parents (see, especially, Dierking *and* Falk, 2001). It is highly likely that changing teaching approaches from the transmission of information into situations of enquiry and questioning will be appealing but this is not a fundamental reason for seeking to develop scientific thinking. Equally, early childhood experiences where questioning can be encouraged and developed in constructive ways will be important. However, there is still the fundamental question about the formal teaching situation: can scientific thinking be taught; if so, how and when? If scientific thinking is so important, then it is essential to ask if it can be taught, how it can be taught, when it can be taught, recognising that the answer to each of these three questions depends on the answer to the previous question.

Zohar (2003) suggests some kind of activities for teachers help to develop the students' scientific thinking skills and these are now summarised:

(1) Asking questions; What is it? Where does it come? How does it happen?
(2) Discussing popular science mysteries.
(3) The right answer is one that accords most closely with the facts.
(4) Performing unusual experiments.
(5) Investigating the environment.
(6) Constructing working models.
(7) Studying interesting objects.
(8) Making connections or considering amazing facts.

This list is full of positive and attractive suggestions which are integral to the practices of good and stimulating teachers. It is highly unlikely that, on their own, such an approach will generate scientific thinking. Indeed, such activities pose other questions. In a curriculum where, in most countries, time is very limited in the attempt to 'cover' the syllabus and where the rewards so often come from the correct recall of facts or the correct application of procedures, where does the hard-pressed teacher find the time (and the energy) to develop such activities?

Womack (1988) tends to come up with parallel, but very idealistic, recommendations: teachers should have more practical aims; children should be handling materials, discovering their properties and observing their behaviour under different conditions; there should be much discussing and recording of information; teachers should be encouraging children to generalise about happenings not yet observed and to offer explanations as to why things behave as they do. He goes on to suggest that children should carry out simple experiment just to see what happens or to test an idea. At the later primary stages, he argues for the children to be encouraged to make hypotheses to explain a set of results or to predict what may happen under certain conditions. All this assumes that scientific thinking is accessible at primary stages and that such activities are possible to carry out with the aims in mind.

Zimmerman (2007) argues that the goal of an experiment is to test a hypothesis against an alternative, whether it is a specific competing hypothesis or the complement of the hypothesis under consideration (see Simon, 1989). This is widely agreed but how to do it under the pressures of a school situation is not so easy. Gold (2002) has a simple answer when he emphasises that the teachers must be trained to teach pupils how to think. The evidence from recent research suggests very strongly that this is highly unlikely to be successful (Carroll, 2005; El-Sawaf, 2007).

Kong (2007) argues that evidence shows that critical thinking dispositions of experienced teachers can be enhanced through appropriate courses. This is consistent with the findings of Carroll (2005) and El-Sawaf (2007). There is no evidence that this transfers into changed teaching practices in that the curriculum and assessment constraints in the schools are too powerful (see El-Sawaf, 2007) although Halpern (1998) asserts that the goal of instruction designed around open-ended questions will help students to become better thinkers is transferable to real-world, out-of-the-classroom situations. Of course, it is essential that teachers should know what it is like to develop their own thinking and to be themselves thinking scientifically if they are to be able to help the pupils (Golding, 2005).

One widely used tool for clarifying thinking skills (Fisher, 1995) has been Bloom's Taxonomy (Bloom and Krathwohl, 1956):

	Cognitive goal	Examples of Thinking
1	Knowledge	What you know or remember
2	Comprehension	Describe in your own words what it means; explain, compare, relate
3	Application	How can you use it?; What you know is used to solve problems
4	Analysis	What are the parts, the order, the reasons why?
5	Synthesis	How might it be different, put together, develop?
6	Evaluation	How would you judge it?, Does it succeed, Why do you think so

Table 7.3 Summary of Six Levels from Bloom's Taxonomy

There is no doubt that the taxonomy has offered a language to teachers which has proved helpful in considering the cognitive processes in various activities. It has generated a vast amount of literature, much of which is arguing for greater emphasis on the so-called 'higher order thinking skills' (see Zoller, 2000a). However there has been a great lack of research on the 'how to achieve' such skills or 'how to assess' such skills, some notable exceptions being Johnstone *et al.*, (1981), Byrne and Johnstone (1983), Byrne *et al.*, (1994), Clarkeburn *et al.*, (2000) although much is set at university level.

Thus, typically, Richard (1985, page 37) sees the categories of the taxonomy as useful "*as a framework for viewing the educational process and analysing its working and also analysing teachers' success in classroom teaching*". He argues for the importance of the higher order skills and that teachers should use questions that call for analysis, synthesis, and evaluation. All this is positive but it offers no evidence that such skills are attainable. If scientific thinking is to be seen as some composite of higher order thinking skills, this does not offer a clear way forward.

Holbrook and Devonshire (2005) do offer a way forward. They discuss how the design and implementation of an online practical activity has been successfully used to simulate scientific thinking and hence encourage students to think like a research scientist, working with second and third year undergraduates in physics and oceanography.

Kong (2006) notes that teachers play a very important part in moulding the next generation of effective citizens in a rapidly changing world, arguing for the importance of training of teachers. Of course, this assumes that such training can, in fact, develop the skills to teaching scientific thinking. Martin (1984) assumes that this is possible in arguing for the explicit discussion of the cognitive and metacognitive processes during teacher training.

At school level, Swarts and Parks (1994) have shown that the more explicit the teaching of thinking is, the more students will learn the processes of thinking and their applications. Studies have also indicated that students score higher on critical thinking tests and standardised achievement tests (Redfield and Rousseau, 1981) when teachers adopt higher-order cognitive questioning techniques. In order to impart thinking skills effectively to students, there has to be, first of all, a paradigm shift in the teacher's attitude, knowledge and practice pertaining to the teaching thinking movement. Thus, the pre-service teacher education programme needs to be reviewed in response to the needs created by the thinking skills movement. McKinnon and Renner (1971) and Lawson and Snitgen (1982) do offer some encouragement that such skills can be learned and or improved even at the adulthood level.

Edwards (2005) suggests a step by step approach and argues that it is important to focus on one or two particular skills, such as analysing, and then build up the repertoire from there. Finally, the skills should be integrated into the teacher's regular lessons. This assumes that schools will make the time available for lessons to teach such skills, that they are best taught in generic terms, and that they will transfer into normal subject teaching.

Serumola (2003) draws attention to a strange situation where many curriculum documents relating to science education at school level make reference to the desirability of teaching scientific thinking skills (although they do not always use the same phrase) while, at the same time, defining the syllabus in terms of the content to be mastered. He quotes a Scottish Office Education Development document as typical of this kind of thinking: "*The major aim of science education is to encourage pupils to think and act as responsible scientists through providing opportunities for them to acquire knowledge and understanding of relevant concepts and through practising the problem-solving and practical skills associated with the scientific process of enquiry*". (SOED, 1994, p.6, underlining added). What is meant by 'problem-solving and practical skills' or 'the scientific process of enquiry' is left unclear.

Dewey (1998, page 28) paints a not-very-encouraging but probably realistic picture when studying how people think and draw conclusions. He found that ideas that run contrary to hopes and wishes tend not to be taken in; most people jump to conclusions; and all fail to examine and test their ideas because of their personal attitudes. He noted that, when people generalise, they tend to make sweeping assertions: thus, from a limited amount of information, the tendency is to make a generalisation covering a wide field. Overall, there is the observation of the powerful influence wielded by social influences that have actually nothing to do with the truth or falsity of what is asserted and denied.

Dewey (1998) also notes the kind of underpinning skills and attitudes which need to be encouraged in order to develop thinking skills, these including a freedom from prejudice or anything which might close the mind and make it unwilling to consider new problems and entertain new ideas, a wholeheartedness in learning and responsibility for learning.

7.9 Some Conclusions

In considering critical thinking, an enormous number of publications exist discussing what is meant by this. There is general agreement that such skills are highly desirable and should be integral in the school and university curriculum. There are fewer papers outlining ways by which it might be achieved and very few which offer evidence on its assessment or achievement.

Scientific thinking, the scientific method and the scientific attitude also occur widely in the literature and there is considerable overlap between the three ideas. Many curriculum documents state that the development of such skills is part of the process of teaching in the sciences but few offer clear descriptions and there is, again, a great shortage of papers which discuss achievement and assessment.

The aim of the sciences might be seen in terms of offering insights and understanding about the world around while the scientific method might be seen as the approach adopted in the sciences for that purpose. Scientific thinking is the type of thinking intrinsic to the scientific method (but not exclusive to it). Critical thinking might be conceptualised as something much broader and which might be important in all disciplines. This can be presented in very simple form in figure 7.6.

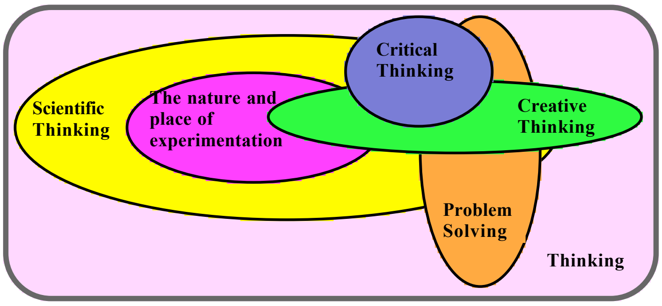


Figure 7.6 Various Kinds of Thinking

The suggestion in figure 7.6 is that the nature and place of experimentation is an important part of scientific thinking. To illustrate this, it is possible to bring together the conclusions from the many papers discussed in this chapter on scientific attitudes, scientific thinking (or method) and critical thinking. The conclusions were analysed to look for the key ideas the authors saw as integral to the various thinking processes. The results are presented in table 7.4, the numbers indicating the number of authors who used the phrases concerned.

	Scientific Attitude	Scientific Thinking or Method	Critical Thinking
thinking correctly			2
giving reliable answers	1	2	3
controlling variables	1	5	
judgement			3
making measurements	1	1	1
explaining	1	5	1
drawing conclusions	2	3	5
classifying		2	
sorting the true from the false			1
considering causation		1	
asking question		3	2
identifying problems	1	2	2
observing	1	4	2
making hypotheses	1	11	
examining test data	1	7	
experimenting	1	8	
using evidence	1	6	4
using logic	1	2	2
collecting data or gathering information		7	2
discovering	1	2	
analysing		5	3
justifying scientific knowledge		1	1
making decision			1
problem - solving	1	4	1
arguing		1	3
looking at basis of belief		1	1
evaluating assumption	1		3
revising hypotheses		3	
studying nature		1	
challenging		1	
suggesting solution or comparisons		1	
having a sceptical attitude		3	
being open-minded	1		1
deducing		1	
inducing		1	

Table 7.4 Different Kinds of Thinking

From this analysis, it is very clear that phrases like making hypotheses, examining test data and experimenting feature strongly in the scientific thinking or method column (and also show in the scientific attitude column where there are very much fewer papers). Such phrases do *not* occur as part of critical thinking. This is the key feature of scientific thought which makes it different from the more general critical thought. Reid and Serumola (2006, 2007) made this the focus of their enquiry by asking if the pupils aged 12-15 had any appreciation of the place and nature of the experiment in their studies in science.

Figure 7.7 attempts to bring this together.

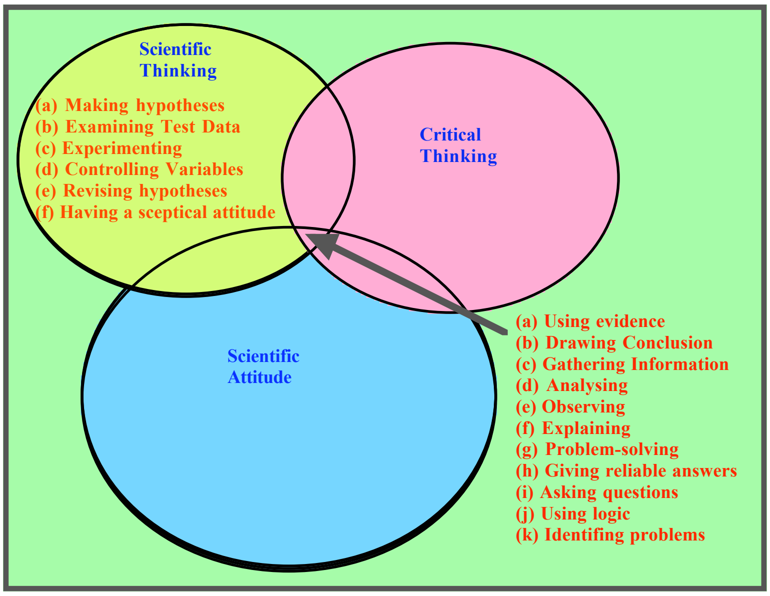


Figure 7.7 Scientific Thinking: what makes it Different?

Thus, the unique characteristics of scientific thinking relate to the nature, place and handling of experimentation, including the place of hypothesis formation.

Chapter Eight

Scientific Thinking and Other Measurements

8.1 The Problem

In reviewing the literature, an attempt was made to see what are the characteristics of scientific thinking which makes it uniquely different from other kinds of thinking, especially critical thinking. The key differences lie in experimentation. Scientific thinking involves the development and use of experiments to gain evidence to support, modify or reject hypotheses.

In thinking about school education in the sciences, two possible (and, perhaps, related) hypotheses arise from this:

(a) Genuine scientific thinking is not accessible until learners have matured developmentally and have sufficient experience of the sciences;
(b) The way the sciences are taught will encourage or hinder the development of such skills.

The first hypothesis is suggested by the observations of Piaget (1964). Indeed, he suggested that hypothesis formation was a skill which developed in the age range of 12-15 approximately. However, the right teaching and experiences may be critical. Nonetheless, it does seem unlikely that handling hypotheses is a skill which is likely to be accessible during the primary ages (up to about age 12). A key limiting factor is the growing capacity of working memory which has only reached a mean of 5 by age 12. It is unlikely that there is enough processing space up to that age to handle the manipulation of the ideas required for hypothesis formation (Johnstone *et al*., 1997).

Thus, we now have a working picture of what is meant by scientific thinking skills and have raised the question whether they are accessible at school level.

The task of the next few chapters is to explore whether they can be measured or, indeed, can be taught.

8.2 An Attempt at Measurement

The work of Reid and Serumola (2006) suggested that there was more or less no evidence of scientific thinking up to age 15. This work was carried out in Botswana and Scotland, with two very different science curricula in operation. They found, however, few differences between the two countries in pupil abilities to think scientifically. They simply did not understand the nature or place of experimentation as a way of testing hypotheses up to age 15.

In this study, students aged 16-18 will be involved. Five measurements were made

A test of scientific thinking;
A physics test seeking to test understanding;
Use of available examination data;
Interpretation of a self report survey;
Working memory capacity measurement.

A sample of 809 students was involved, drawn from years 10-12 from typical schools in the United Arab Emirates. Care was taken to select the sample so that it reflected a diversity of schools and catchment areas although the society in the Emirates is remarkably cohesive. Boys and girls schools were involved, urban and more rural, government and private.

Each measurement is now described in turn, along with the descriptive statistics of the data obtained.

8.3 A Test of Scientific Thinking

This test was developed in relation to the Physics curriculum. In order to be acceptable to teachers and students, the questions had to be seen as having some connection with physics which was taught. The objective and the aim of the test is to measure students scientific thinking skills. When these were analysed in chapter 7, it was found that the key feature which makes scientific thinking skills unique lies in the place of the experimental in gaining evidence. The test had six questions, each of which aimed to measure one aspect of such skills.

Question	Intended Measurement
1	Interpreting experimental observations
2	Cause and effect relationships
3	Looking for evidence
4	Explaining experimental observations by generating hypotheses
5	The place of evidence (especially experimental) in drawing conclusions
6	Looking for key data (critical data)

Table 8.1 Scientific Thinking Test Specification

The test was designed by selecting from possible test items which seemed to be appropriate in measuring the desired skills. Four of the questions used were new while two (questions 5 and 6) were drawn from the work of Serumola (2004) so that some kind of comparison might be made with his findings with a younger age group. The test items were considered by a small group of experienced teachers before the six questions used were selected. The test was then translated into Arabic and the translation checked.

The test was used with students from grades 10, 11 and 12, following the physics course. It was made clear to them that the marks in the test would not influence their school grades in any way. 20 minutes was allowed.

The test was made up of six questions but question 1 had two separate parts. Each question was marked and then the marks for each question were scaled to be out of one, both parts of question 1 being scaled separately. The total maximum mark was 7.

With large samples and adequate time to complete the test, it is likely that test reliability would be satisfactory (see Reid, 2003). However, there is no certainty that the test was actually measuring what it was intended to measure. It was hoped that, by discussing it during development with several experienced teachers, the validity would be acceptable, but the outcomes have to be interpreted with caution.

The test is now shown in full.

UNIVERSITY of GLASGOW

University of Glasgow

Centre for Science Education

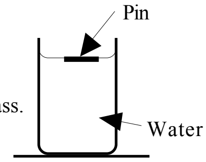
This questionnaire is a part of a project investigating how you think when you learn physics.
All information obtained will be treated in complete confidence.
Please complete this questionnaire about your studies in physics as honestly as possible.

Your Name ....

Name of school: ....

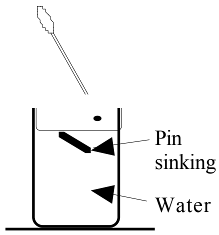
Grade: .... Class: ....

(1) If we carefully lay a metal pin across a water surface, it will actually float on water.
Which of the following statements are ***possible explanations***.
(Tick as many as you wish)



☐ Particles(molecules) of the liquid form stronger bonds with each other than with particles of glass.
☐ The links between particles in the metal are not strong.
☐ The pin is less dense than the water.
☐ Water molecules interact with each other more strongly than they interact with the surface of the pin.
☐ The water molecules attract each other so strongly that the weight of the pin is not enough to break their bonds.
☐ Pins like this float on water

If we now put a drop of soap solution onto the water, the pin will sink.
Which of the following statements are ***possible explanations***.
(Ticks as many as you wish)



☐ The pin is more dense than the water.
☐ Particles of the liquid form stronger bonds with each other than with particles of glass.
☐ The links between particles in the metal are not strong.
☐ Water molecules interact with each other more strongly than they interact with the detergent.
☐ Dissolved substances change the nature of interaction between molecules in the solvent.
☐ The detergent weakens the interactions between water particles

(2) Here are six statements. Place them in pairs where one statement could have caused the other statement

(A) A boy went fishing at the lake
(B) He went with a friend
(C) He ate some green berries
(D) He caught two fish
(E) He was late home
(F) The next day he was very sick

Use letters to show which statement caused which statements

☐ caused ☐
☐ caused ☐
☐ caused ☐

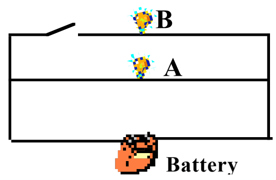
(3) Imagine you lost your bicycle. You want to describe your bike to your friends so that they might find it.
Which of the following statements would help find your bike?
(Tick as many as you wish)

My bicycle....
☐ Is red
☐ Was owned by my brother
☐ Has 10 speed gears and racing handle bars
☐ Was a birthday present
☐ Has rubber tyres
☐ Has a bent front mudguard

(4) Nora and Omar set up the circuit shown alongside. They predicted that, when they closed the switch, bulb B would light up and bulb A would be unaffected.

When they did close the switch, they found that bulb B DID light up. However, they noticed that bulb A ***dimmed*** very slightly.

Which of the following are possible explanations for what they observed?
Tick as many as you like.



- ☐ The wires have a small resistance.
- ☐ Bulb B is of lower resistance than A.
- ☐ The battery has some resistance.
- ☐ When bulb B lights, it reduces the current to bulb A.
- ☐ Bulb B takes voltage from bulb A.
- ☐ Bulb A is of lower resistance than B.
- ☐ Bulbs A and B are in parallel to each other.

(5) Mohammed has been studying global warming and wonders how scientists know what is actually the truth about global warming. His friend suggested several ways to find the answers. These are listed:

A Read scientific books
B Talk to experts like university professors
C Carry out experiment to test the idea global warming
D Collect as much information as possible about global warming
E Assume global warming is true and act accordingly
F Use intelligent guesswork
G Look at information which has already been gathered through research
H Accept what majority of people believe is true about global warming

Arrange these suggested answers in order of their importance by placing the letters A,B,C...etc, in the boxes below. The letter which comes first is the most important and the letter which comes last is the least important for you.

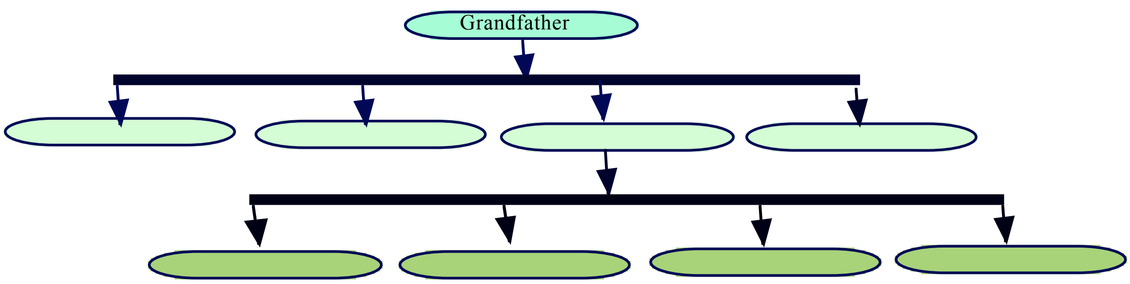
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Most important Least important

(6) The table below gives information about a family, from grandfather to grandchildren. It is the year 2005.

Grandfather Still alive in the year 2005	***Aunt*** 10 years younger than uncle 2	***Uncle 1*** 4 years younger than aunt
Father In 1965, he was same age as grandfather in 1932 and 4 years younger than Uncle 1	***Uncle 2*** 2 years younger than father	***Sara*** In 1995, her age was one-fifth the age of her Aunt
Ahmad In 1990, his age was half the age of Sara	***Abdulla*** 2 years younger than Ahmad	***Maryam*** 2 years younger than Abdulla

Use the information given in the table to complete the family tree diagram below, with grandfather at the top.



At the moment, it is impossible to calculate the age of the grandfather.
What ***other piece of information*** would you need about ***Maryam*** to work out the ***age of her grandfather*** in the year 2005?

....

The test statistics are shown in table 8.2 while the distributions are shown in Figure 8.1.

N = 809	Year Group	Sample	Maximum Mark	Minimum Mark	Mean	Standard Deviation
Scientific Thinking	*Year 10*	288	6.3	0.3	4.2	1.3
	Year 11	257	6.3	0.5	4.6	1.1
	Year 12	264	7.0	1.5	4.9	1.0

Table 8.2 Descriptive Statistics: Scientific Thinking Test

The mean marks and standard deviations show that the scientific thinking test was of a reasonable difficulty, giving a good spread of performance. This is illustrated by the histograms in figure 8.1. The mean mark varies significantly with age:

t-test (year 10/11) = 3.9, $p < 0.001$;
t-test (year 11/12) = 3.9, $p < 0.001$;

One way ANOVA: $F = 30.1$, $p < 0.001$.

It is not easy to see why the performance varies in this way.

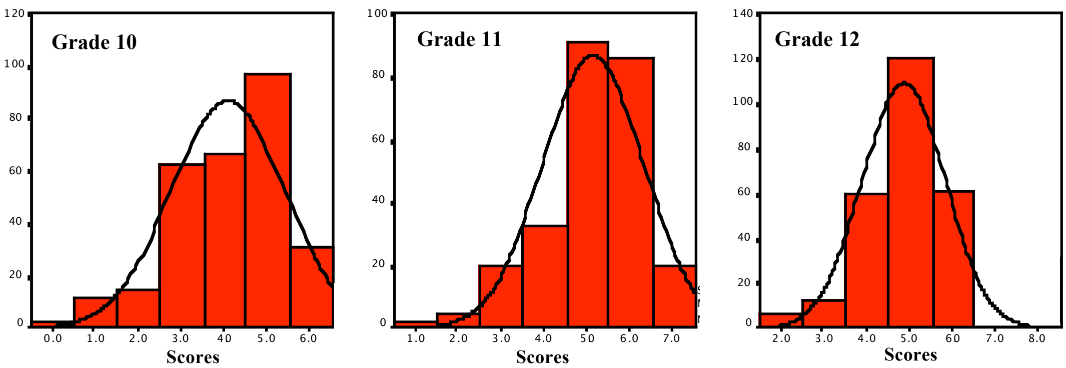


Figure 8.1 Descriptive Statistics: Distributions

8.4 Understanding Physics

Physics examinations in The Emirates tend simply to test recall of facts or procedures using short answer approaches. Three examples illustrate typical questions:

(1) Write between the brackets the scientific term for the force which exists between any two objects (.................).

(2) Put circle around the right answer:
A student carries his schoolbag of weight 50 N along a horizontal road for a distance of 10 m. The work he does against the gravity is :
(a) 500 J (b) zero (c) 5 J (d) 0.2 J

(3) Match the phenomena to their physical explanations by inserting the correct numbers in the brackets.

1	Viscosity	(..........)	Floating ships
2	Surface Tension	(..........)	The rise in Kerosene wick
3	Capillarity	(..........)	An insect walking on the water's surface
4	Archimedes Principle	(..........)	Oiling and lubricants

In looking at scientific thinking, it was decided to design a test which reflected the *understanding and application* of physics ideas to see how these skills related to the recall-recognition emphasis of Emirates examinations and also to see how these skills related to scientific thinking. It is possible that those who are best at recall-recognition might be more capable of scientific thinking or it is possible that those who can apply ideas because they have some understanding of them might be more capable of scientific thinking.

The test was designed so that it was based on the physics which was accessible for years 10, 11 and 12, had no obvious gender imbalance and the aim of the test was to measure the extent of student understanding of these basic concepts in physics. This was done by asking the students to apply ideas.

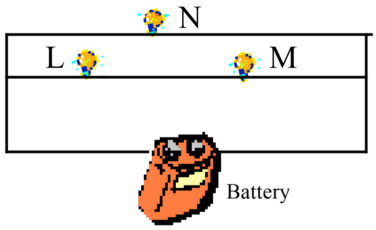
Based on the experience of the physics curriculum in the Emirates and the types of understanding which should be possible, the test was constructed, scrutinised by those with physics expertise and physics education experience. It was adapted and modified before being translated into Arabic, the translation being checked. One mark was given for each right answer, the total maximum score being 16.

The full test is shown overleaf.

UNIVERSITY of GLASGOW

Your Name ....
Name of school ....
Grade .... Class ....

(1) In the circuit below there are 3 identical lamps: L, M and N.

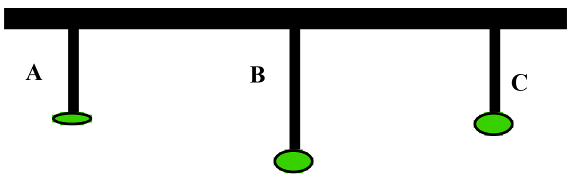


When M is removed from its socket, the brightness of N does not change. Here are six statements related to what has happened
Look at the statements below. All are true.
Select all the statements which ***offer an explanation*** why the brightness of N does not change
Tick as many as you wish.

Tick here	Tick here	Statement
A		The current flowing through N does not change
B		resistance
C		L and N have the same resistance
D		L and M are in series and both are parallel to N
E		There is now no current flowing through L when M is removed
F		The voltage across N has not altered

(2) You have three pendulums.
A and C have the same length of string.
B and C have an equal weight attached while A has a smaller weight.

Suppose you wanted to do an experiment to find out if changing the length of a pendulum changed the amount of time it takes to swing back and forth.
Which pendulums would you use for the experiment.

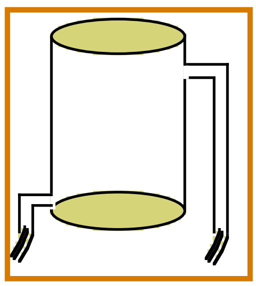


A&B ☐ B&C ☐ A&C ☐ A,B&C ☐

(3) Consider a water container. If it is filled with water ***to the top***, water can escape from the pipe at the bottom or the pipe nearer the top. Both pipes have the same diameter.

Think of the flow rate of water from each pipe when the container is full of water.
Which of the following is true?

☐ There is a higher flow rate from the short pipe;
☐ There is a slower flow rate from the short pipe;
☐ There is a same flow rate from both pipes.



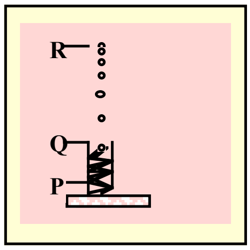
Explain your choice of answer:

....

(4) The figure below shows a multiflash photograph of a small ball being shot straight up by a spring. The spring, with the ball on top was initially compressed to the point marked P and released.

The ball left the spring at the point marked Q and reached its highest point at the point marked R.

Assume that the air resistance was negligible.



Here are five statements about this experiment. Tick ***all*** the statements which are ***true***.

	Tick here	Statement
A		The velocity of the ball was decreasing on its way from point Q to point R
B		The acceleration of the ball was greatest at point Q
C		The acceleration of the ball was the different at P and Q
D		The velocity of the ball was increasing on its way from point Q to point R
E		The acceleration of the ball was greatest just before it reached point R

The velocity of the ball was greatest just as it reached point Q (still in contact with the spring). In two sentences, explain why this has to be true:

....

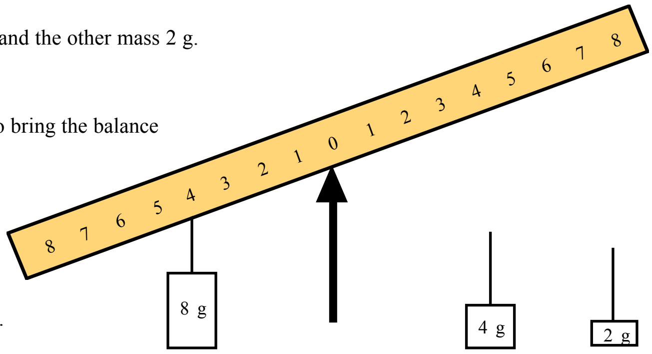
....

....

(5) Khalid and Reem have two masses. One mass 4 g and the other mass 2 g.

Here is a balance with an 8 g mass attached.

They wonder if it is possible to use the two mass to bring the balance level again.



Which of the following is true?
*Tick **all** the statements which are true.*

☐ Equilibrium cannot be achieved because the sum of the 4 g and 2 g mass is less than 8 g.

☐ Equilibrium can be achieved by placing the 4g mass at hole number 2 on the right and the 2g mass at hole number 1 on the right.

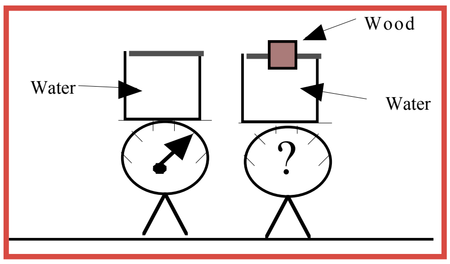
☐ Equilibrium can be achieved by placing the 4 g mass at hole number 4 on the right and the 2 g mass at hole number 8 on the right.

☐ Equilibrium can be achieved by placing the 4 g mass at hole number 8 on the right and the 2 g mass at hole number 0.

☐ Equilibrium can be achieved by placing the 4 g mass at hole number 5 on the right and the 2 g mass at hole number 8.

☐ Equilibrium can be achieved by placing the 4 g mass at hole number 7 on the right and the 2 g mass at hole number 2.

(6) A pair of identical containers are filled to the brim with water.
One has a piece of wood floating in it.
What is the total weight on the right hand balance ?



☐ The balance on the right shows the higher reading.

☐ The balance on the right shows the smaller reading.

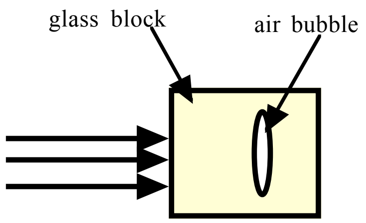
☐ Both balances read the same

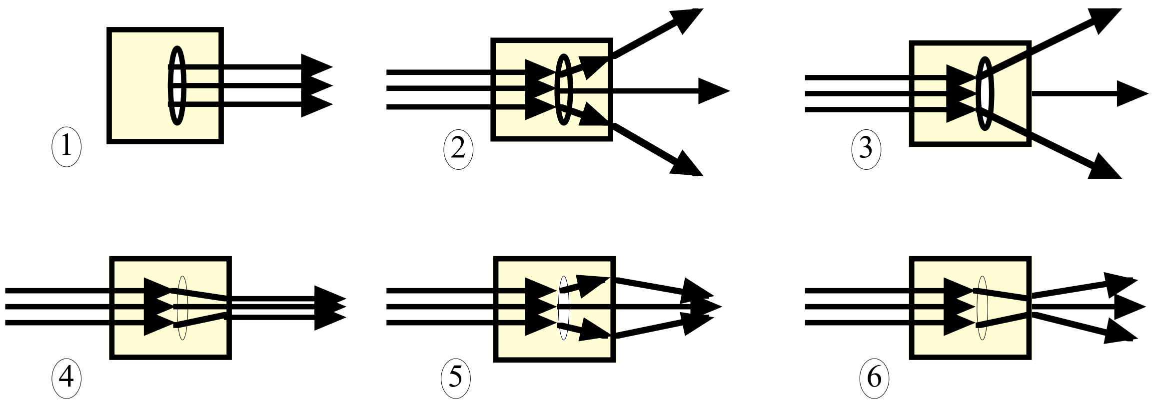
(7) Here are a picture showing three parallel rays of light which are incident on a glass block containing an air bubble.

Which picture shows the path of the rays through the block correctly?

Tick one box:

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐



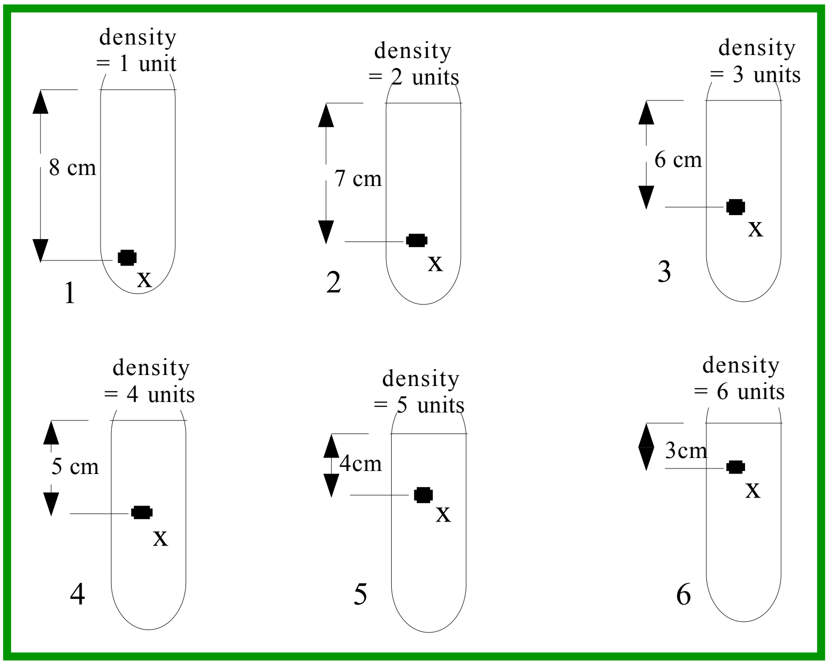


(8) The pictures below show six liquids of different density contained in a separate identical test tube.

The density of each liquid is given in the diagram.

Looking at all six tubes, in which tubes are the pressures greatest at point X?
(Tick as many as are correct answers)

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐



The test statistics are shown in table 8.3 while the distributions are shown in Figure 8.2.

N = 809	Year Group	Sample	Maximum Mark	Minimum Mark	Mean	Standard Deviation
Physics Understanding	*Year 10*	288	16.0	0.9	6.8	2.5
	Year 11	257	15.0	1.0	7.5	2.4
	Year 12	264	14.0	2.0	8.0	2.5

Table 8.3 Descriptive Statistics: Physics Understanding Test

As might be expected, the mean performance rises with age as they gain more experience and confidence in physics:

t-test values are 3.2 (year 10 and 11), $p < 0.01$;
and 2.5 (year 11 and 12), $p < 0.05$;

while ANOVA gave an F value of 16.6, $p < 0.001$.

The mark distributions show that the scientific thinking test was of an appropriate standard and spread the students quite well (figure 8.2).

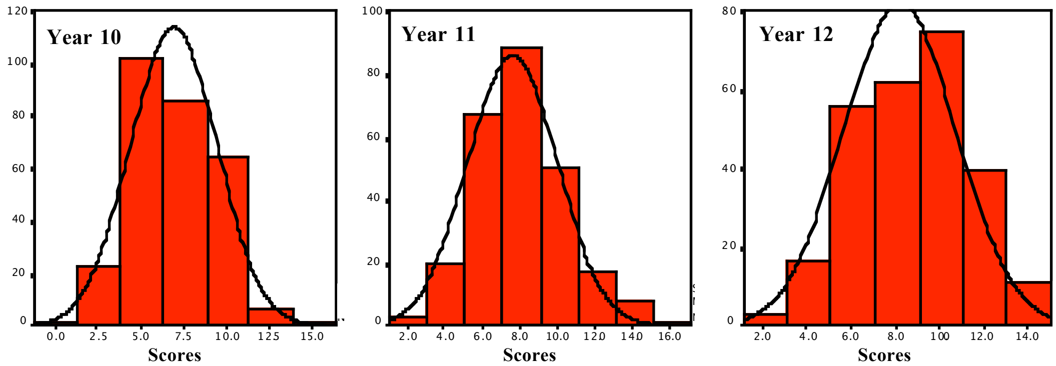


Figure 8.2 Descriptive Statistics: Distribution of Marks

8.5 Examination Data

The examination data were the marks obtained by the students at the end semester national examinations. The descriptive statistics for the examination marks are shown in table 8.4

N = 809	Year Group	Sample	Maximum Mark	Minimum Mark	Mean	Standard Deviation
Physics Examination	*Year 10*	288	100	15	70.5	20.9
	Year 11	257	100	18	75.2	22.0
	Year 12	264	100	9	68.9	25.9
Chemistry Examination	*Year 10*	288	100	23	74.8	19.0
	Year 11	257	100	20	75.0	18.8
	Year 12	264	100	7	70.4	25.0
Biology Examination	*Year 10*	288	100	20	72.4	21.2
	Year 11	257	100	28	76.0	18.8
	Year 12	264	100	11	70.8	25.3
Mathematics Examination	*Year 10*	288	100	5	72.6	24.2
	Year 11	257	99	6	66.0	21.2
	Year 12	264	100	14	73.7	21.8

Table 8.4 Descriptive Statistics: Examination Data

Means tend to be high with very large standard deviations in all subjects. This suggests that quite large numbers are not performing well although the majority gain good marks. This can be seen in the histograms for physics showing the spread of marks for each subject at each of the three levels.

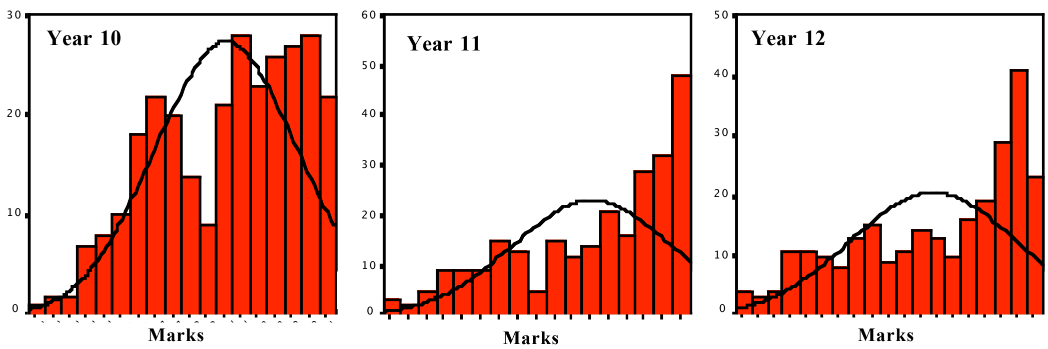


Figure 8.3 Marks Distributions: Physics National Examinations

What is striking about the distributions is that there appear to be two normal distribution curves within each overall distribution, suggesting two populations. One population performs extremely well while the other performs relatively badly, giving a much flatter distribution. The suggested distributions are marked on by hand.

Looking at the other three subjects, similar multiple distributions seem to occur in them all. There is a group which does well while the other part of the year group generates marks which are spread widely but have a much lower mean.

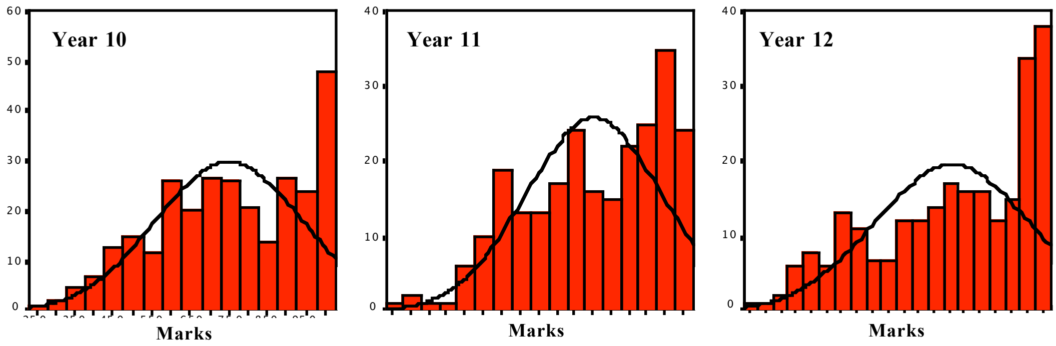


Figure 8.4 Marks Distributions: Chemistry National Examination

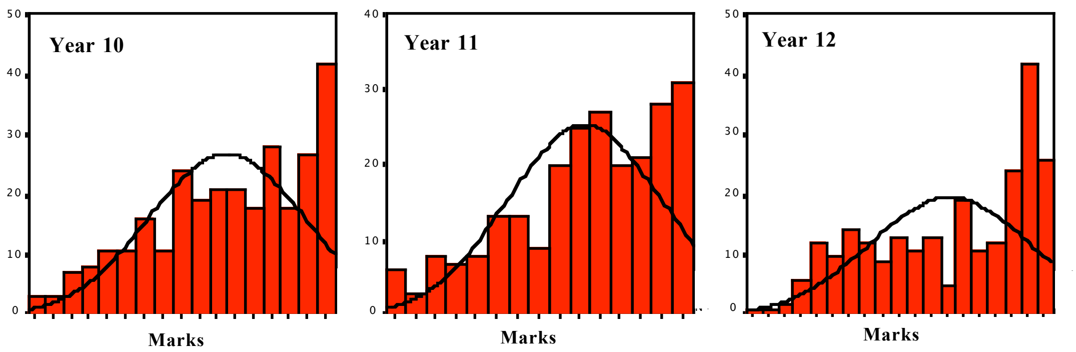


Figure 8.5 Marks Distributions: Biology National Examinations

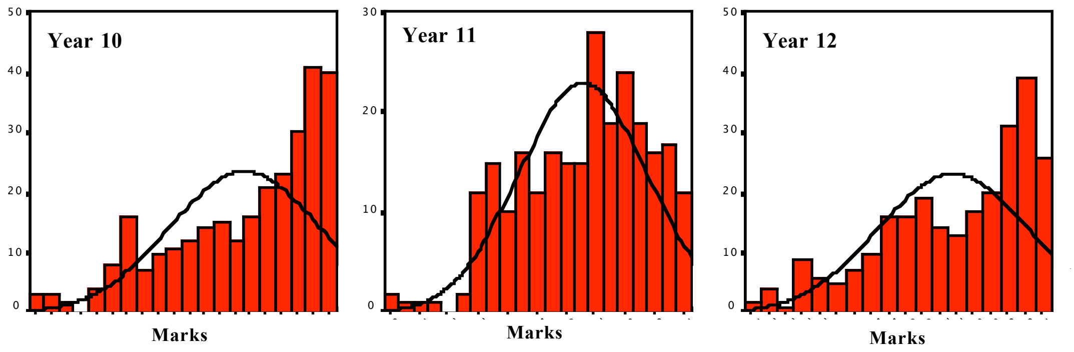


Figure 8.6 Marks Distributions: Mathematics National Examinations

Interpreting the double distributions cannot be done with certainty. It is possible that they reflect two parts in the population: those who can cope with the maths-science range of subjects well and those who are rejecting such studies, seeking other options. However, it could reflect those who cope well with the typical short answer type examinations and those who do not.

8.6 Working Memory Capacity

Working memory capacity is known to be the rate controlling step in learning (seen as understanding), thinking, problem solving (see Johnstone, 1997) It is, therefore, possible that it is a rate controlling step in scientific thinking. There are two main methods to measure this: the digit span backwards test and figural intersection test. The digit span test was used here and this is described in full in appendix F. The tester read out a series of numbers to the student group at a fixed pace and then the students had to write down the numbers a second later, in reverse order.

The test statistics are shown in table 8.5 while the distributions are shown in Figure 8.7.

N = 809	Year Group	Sample	Maximum Mark	Minimum Mark	Mean	Standard Deviation
Working	*Year 10*	288	9	4	6.3	1.2
Memory	*Year 11*	257	9	4	6.4	1.2
Capacity	*Year 12*	264	9	4	6.4	1.1

Table 8.5 Descriptive Statistics: Working Memory Capacity

Looking at table 8.5, the mean values are constant. This is exactly to be expected in that Miller (1957) showed that working memory capacity grow with age to approximately age 16 at which stage it was fixed for life. The students are all 16 or older. The mean value is 6.3 from the digit span backwards test. This is a measure of the average number of digits which could be recalled in reverse order. It is known that the mean for adults is 7 and the digit span backwards test always gives up to 1 unit less simply because some of the working memory has to be used to handle the reversal process. Thus, the data and the scores spread (figure 8.7) are in line with expectations. However, it is important to note that the absolute values are not being used in this study, only the order of merit.

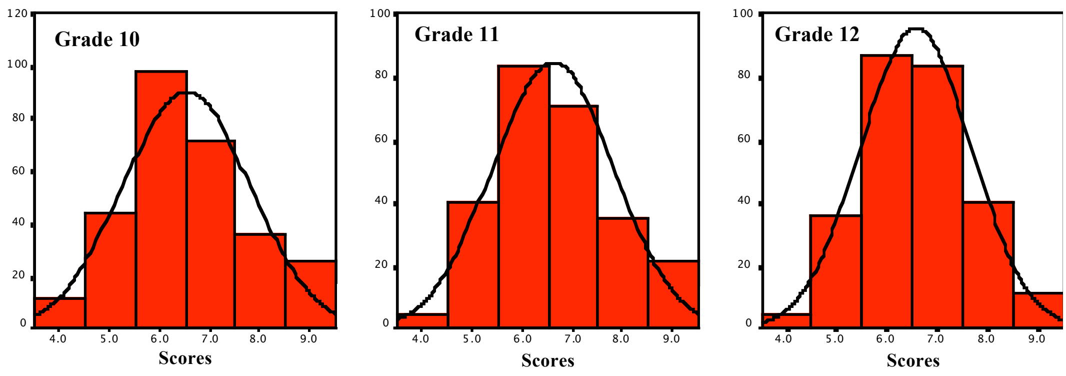


Figure 8.7 Working Memory Scores Distributions.

Test marking is not easy but a standard procedure was adopted to ensure consistency of marking in line with the findings of Mancy (2007).

8.7 Analyses of Data for Whole Sample

The first stage was to consider the data for all three year groups together, a total sample of 809. Pearson correlation was used to relate the scores for working memory capacity, physics understanding and scientific thinking along with the school examination marks (table 8.6). Pearson correlation can be used if the data are integer data, approximately normally distributed (see appendix G).

All years N = (809)	*Working Memory*	*Physics Understanding*	*Scientific Thinking*	*Physics Exam*	*Chemistry Exam*	*Biology Exam*
Working Memory Capacity					buff	p < 0.05
Physics Understanding	0.04				green	p < 0.01
Scientific Thinking	**0.07**	**0.25**			red	p < 0.001
Physics Exam	**0.11**	**0.18**	**0.26**			
Chemistry Exam	**0.09**	**0.21**	**0.21**	**0.80**		
Biology Exam	**0.11**	**0.26**	**0.28**	**0.81**	**0.87**	
Mathematics Exam	**0.11**	**0.21**	**0.21**	**0.74**	**0.77**	**0.76**

Table 8.6 Pearson Correlations

The correlations of working memory capacity with all the measurements give low correlations although many are significant. It might be expected that the correlation with school examinations in the three sciences and mathematics might be low as these examinations tend to use short questions, mainly of a recall nature. A similar pattern of low correlations was found by Hindal (2007) with six school subjects when the examinations were simply testing recall by using short questions.

In the understanding test, the questions were again short and were designed in such a way that they tried to explore understanding without placing too much strain on the working memory: the low correlations show that this was successful. However, it is surprising that the correlations are so low for the scientific thinking test. The items here were not designed specifically to have low working memory demands. Perhaps, the students were simply trying to recall and were not really engaging with the test items.

The physics understanding and the national physics examination only show a correlation of 0.18. This is amazingly low, suggesting that these two tests are measuring something very different. This was explored further using factor analysis. It is also worth noting that the correlations between all the school examinations are extremely high, suggesting in this case, that they might be measuring the same thing. Factor analysis can be helpful here. In factor analysis, the procedure looks for any underlying factors which might account for the observed correlations. However, it cannot identify any factors found, this requiring human judgement.

Principal Components Analysis (one form of factor analysis), using varimax rotation, gives the output shown below. The Scree plot indicates that there are three components. Over 90% of the variance is accounted for by these three. See appendix G for details. Possible names for the three components are shown. Loadings can be thought of as the correlations between the actual measurements and the underlying factors.

N = 809	*Component 1*	*Component 2*	*Component 3*
	Recall and recognition	*Scientific Thinking skills*	*Physics Understanding*
Scientific Thinking	0.15	**0.98**	0.12
Physics Understanding	0.13	0.12	**0.99**
Physics Exam	**0.91**	0.16	0.05
Chemistry Exam	**0.93**	0.06	0.09
Biology Exam	**0.93**	0.13	0.14
Mathematics Exam	**0.88**	0.08	0.10

Table 8.7 Factor Loadings

Firstly, it has to be noted that accounting for 90% of the variance is extremely high, giving great confidence in the analysis. The clear conclusion can be drawn that whatever the scientific thinking test is measuring, it is certainly *not* measuring what the physics understanding test was measuring or what any of the school examinations were measuring. Even more remarkable is that the physics understanding test is completely different from all the school examinations in what it is testing. However, the school examinations all load very highly on to the first factor and this can only be recall.

The analysis shows very clearly (the loadings are either extraordinarily high or very low) that the school examinations are measuring the same basic skill (recall-recognition of facts or procedures) and this is almost exactly the same finding that Hindal (2007) observed when looking at examinations at age 13 with very large samples of pupils in Kuwait. The physics understanding test is an attempt to gain a measure of understanding through application of simple physics ideas. It is sad that there is more or less no overlap between what this test measures and what the national examinations measure.

Of greatest interest is that the scientific thinking test outcomes do not relate to either recall-recognition or to physics understanding. The test was designed to measure scientific thinking. The analysis does *not* show that it is successful in this but it does show that it is *not* measuring recall-recognition or physics understanding.

8.8 Year Group Comparisons

Having looked at the data overall, this section summarises the findings for each year group.

Year 10 all N = 288	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working Memory					buff	$p < 0.05$
Physics Understanding	0.01				green	$p < 0.01$
Scientific Thinking	**0.13**	**0.26**			red	$p < 0.001$
Physics Exam	0.08	**0.26**	**0.35**			
Chemistry Exam	0.11	**0.28**	**0.33**	**0.79**		
Biology Exam	**0.12**	**0.31**	**0.40**	**0.87**	**0.85**	
Mathematics Exam	**0.18**	**0.26**	**0.35**	**0.86**	**0.78**	**0.82**

Table 8.8 Year 10 Correlations

Year 11 all N = 257	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working Memory					buff	$p < 0.05$
Physics Understanding	- 0.01				green	$p < 0.01$
Thinking	- 0.12	**0.19**			red	$p < 0.001$
Physics Exam	0.04	**0.13**	**0.24**			
Chemistry Exam	0.03	**0.15**	**0.19**	**0.83**		
Biology Exam	0.08	**0.14**	**0.18**	**0.81**	**0.89**	
Mathematics Exam	0.08	0.12	**0.19**	**0.83**	**0.84**	**0.80**

Table 8.9 Year 11 Correlations

Year 12 all N = 264	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working Memory					buff	$p < 0.05$
Physics Understanding	0.04				green	$p < 0.01$
Thinking	0.12	**0.20**			red	$p < 0.001$
Physics Exam	0.08	**0.23**	**0.18**			
Chemistry Exam	0.11	**0.25**	**0.17**	**0.81**		
Biology Exam	0.12	**0.32**	**0.23**	**0.79**	**0.87**	
Mathematics Exam	0.10	**0.25**	**0.25**	**0.81**	**0.79**	**0.78**

Table 8.10 Year 12 Correlations

Looking at tables 8.8, 8.9 and 8.10 together shows some common features and some differences. In every case, working memory correlations are low and, mainly non significant. In every case, the inter-correlations between national examinations marks are extremely high. The results from the Physics understanding test correlate less highly with the national examinations in year 11 than the other two years. The results from the Scientific Thinking test correlate more highly with the national examinations in year 10 than the other two years. The reasons for these differences are not obvious.

8.9 Girls and Boys Together

Table 8.11 shows the correlations obtained from all the girls while table 8.12 shows the same data for the boys.

All girls N = 445	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working Memory					buff	$p < 0.05$
Physics Understanding	0.07				green	$p < 0.01$
Scientific Thinking	0.07	**0.15**			red	$p < 0.001$
Physics Exam	**0.13**	**0.20**	**0.23**			
Chemistry Exam	**0.13**	**0.23**	**0.13**	**0.82**		
Biology Exam	**0.12**	**0.27**	**0.21**	**0.81**	**0.88**	
Mathematics Exam	**0.15**	**0.24**	**0.14**	**0.73**	**0.77**	**0.75**

Table 8.11 Correlations: All Girls

All boys N = 364	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working Memory					buff	$p < 0.05$
Physics Understanding	0.01				green	$p < 0.01$
Scientific Thinking	**0.12**	**0.36**			red	$p < 0.001$
Physics Exam	**0.15**	**0.15**	**0.27**			
Chemistry Exam	**0.11**	**0.18**	**0.26**	**0.77**		
Biology Exam	**0.14**	**0.25**	**0.35**	**0.82**	**0.86**	
Mathematics Exam	**0.12**	**0.18**	**0.28**	**0.75**	**0.77**	**0.77**

Table 8.12 Correlations: All Boys

Working memory correlates positively with all other tests and the boys and girls seem to be very similar. The physics understanding test data correlates with all other tests but the boys show a much higher correlation in relation to the data from the scientific thinking test suggesting that the thinking skills use in the scientific thinking test are being used more by the boys in the physics understanding test. Perhaps, this reflects the boys' greater dependence on working things out while the girls are more willing to memorise.

The scientific thinking test also correlates significantly with all other tests for both genders. However, the correlation for the boys is very much higher in every case. Again, this could simply reflect that boys are less willing to make the effort to memorise and rely more on working things out. This is particularly important in a country like the Emirates where girls do not have the same social freedom as boys and, being more restricted to their home, often spend more time working.

8.10 Boys and Girls by Year Group

It is interesting to look at gender differences year by year.

Year 10

year 10 girls N = 158	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working Memory					buff	$p < 0.05$
Physics Understanding	0.11				green	$p < 0.01$
Scientific Thinking	0.05	**0.18**			red	$p < 0.001$
Physics Exam	**0.17**	**0.28**	**0.34**			
Chemistry Exam	**0.18**	**0.28**	**0.27**	**0.80**		
Biology Exam	0.12	**0.35**	**0.38**	**0.85**	**0.86**	
Mathematics Exam	0.15	**0.29**	**0.29**	**0.84**	**0.79**	**0.80**

Table 8.13 Correlations: Year 10 Girls

Year 10 boys, N = 130	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working Memory					buff	$p < 0.05$
Physics Understanding	0.07				green	$p < 0.01$
Scientific Thinking	**0.27**	**0.34**			red	$p < 0.001$
Physics Exam	0.17	**0.26**	**0.39**			
Chemistry Exam	0.08	**0.25**	**0.39**	**0.81**		
Biology Exam	0.12	**0.28**	**0.43**	**0.90**	**0.85**	
Mathematics Exam	**0.21**	**0.24**	**0.43**	**0.89**	**0.79**	**0.84**

Table 8.14 Correlations: Year 10 Boys

The most marked differences between the genders is the correlation of working memory with the thinking test: strong for boys, negligible for girls. This may reflect the tendency for girls to be able to cope with recognition and recall better than boys who have to relying on working it out more. This is consistent with the very high value of the correlation between the thinking test and the physics test.

Year 11

Year 11 girls, N = 141	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working Memory					buff	$p < 0.05$
Physics Understanding	0.02				green	$p < 0.01$
Scientific Thinking	0.05	0.05			red	$p < 0.001$
Physics Exam	0.15	0.09	0.02			
Chemistry Exam	**0.18**	**0.22**	0.13	**0.59**		
Biology Exam	**0.20**	**0.21**	0.14	**0164**	**0.91**	
Mathematics Exam	**0.25**	0.16	-0.11	**0.73**	**0.8**	**0.79**

Table 8.15 Correlations: Year 11 Girls

Year 11 boys, N = 116	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working Memory					buff	$p < 0.05$
Physics Understanding	0.02				green	$p < 0.01$
Scientific Thinking	-0.07	**0.21**			red	$p < 0.001$
Physics Exam	-0.17	0.07	**0.22**			
Chemistry Exam	-0.14	0.09	**0.19**	**0.76**		
Biology Exam	-0.11	0.06	**0.21**	**0.78**	**0.88**	
Mathematics Exam	-0.17	0.12	**0.28**	**0.85**	**0.81**	**0.75**

Table 8.16 Correlations: Year 11 Boys

There are quite remarkable differences between the genders here. Working memory does not correlate with anything significantly with the boys but correlates significantly with three of the national examinations for the girls although the values are low. It is very difficult to explain this. Clearly, the year 11 group is showing a different pattern of results when compared to 10 and 12. This is the first year when the sciences are taught separately.

As before, the thinking test shows strong correlations with all other tests for the boys but not for the girls. The physics test is correlated significantly with national examinations for the girls but not for the boys. The pattern of correlations suggests that the national examinations are in some way different for this year group compared to year 10.

Year 12

Year 12 girls, N = 146	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working Memory					buff	$p < 0.05$
Physics Understanding	0.07				green	$p < 0.01$
Scientific Thinking	0.16	0.09			red	$p < 0.001$
Physics Exam	0.02	0.16	0.11			
Chemistry Exam	0.03	**0.23**	0.07	**0.88**		
Biology Exam	0.05	**0.24**	0.13	**0.78**	**0.87**	
Mathematics Exam	-0.03	**0.21**	0.15	**0.80**	**0.80**	**0.75**

Table 8.17 Correlations: Year 12 Girls

Year 12 boys, N = 118	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working Memory					buff	$p < 0.05$
Physics Understanding	- 0.00				green	$p < 0.01$
Scientific Thinking	0.09	**0.36**			red	$p < 0.001$
Physics Exam	0.18	**0.35**	**0.21**			
Chemistry Exam	**0.22**	**0.29**	**0.26**	**0.72**		
Biology Exam	**0.22**	**0.43**	**0.34**	**0.79**	**0.86**	
Mathematics Exam	**0.25**	**0.30**	**0.33**	**0.80**	**0.77**	**0.80**

Table 8.18 Correlations: Year 12 Boys

The girls show no significant correlation of working memory with anything while the boys show positive correlations with national examinations, similar to the previous pair of tables.

As before, the thinking test is highly correlated for the boys with everything while it is not significantly correlated for the girls.

8.11 Gender and Schools

Section 8.8 revealed that correlations for boys were often larger when compared to those for the girls. This was explained by noting that girls are often more willing to memorise . The boys, therefore, often relied more on working things out. It is possible to bring the data together to see if any patterns are obvious, with three year groups, two types of schools (government and private) with the two genders. Samples are: N (boys) = 364, N (girls) = 445; N (government) = 233, N (private) = 576. The general overall pattern is summarised in (table 8.19).

Year 10, 11 and 12 All Schools	Working Memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemistry Exam	Biology Exam
Working memory						
Physics Understanding	–					
Scientific Thinking	+	+				
Physics Exam	+	–	+			
Chemistry Exam	–	–	+	–		
Biology Exam	+	–	+	+	–	
Mathematics	–	–	+	+		–

\+ means boys show higher correlation than girls
– means boys show lower correlation than girls

Table 8.19 Working Memory and Gender

This shows that boys correlations tend to be larger for the thinking test. This can be split down to show the year groups and the two kinds of schools (table 8.20).

Year 10,11,12 goverment & private schools	Working memory	Physics Understanding	Scientific Thinking	Physics Exam	Chemstry Exam	Biology Exam
Physics Understanding	1 [+, –] 2 3 [,] 4 5 [,] 6					
Scientific Thinking	1 [+, +] 2 3 [,] 4 5 [, –] 6	1 [+, +] 2 3 [+, +] 4 5 [+,] 6				
Physics Exam	1 [+, +] 2 3 [–,] 4 5 [,] 6	1 [+, –] 2 3 [–,] 4 5 [+, +] 6	1 [+, +] 2 3 [+, +] 4 5 [+,] 6			
Chemistry Exam	1 [–, –] 2 3 [,] 4 5 [, +] 6	1 [–, +] 2 3 [–, –] 4 5 [+,] 6	1 [+, –] 2 3 [+,] 4 5 [+, –] 6	1 [+, –] 2 3 [+, –] 4 6 [–, –] 6		
Biology Exam	1 [+, +] 2 3 [,] 4 5 [, +] 6	1 [–, +] 2 3 [–, –] 4 5 [+, +] 6	1 [+, –] 2 3 [+,] 4 5 [+, –] 6	1 [+, +] 2 3 [+, –] 4 6 [+, +] 6	1 [, –] 2 3 [+, –] 4 6 [–, +] 6	
Mathematics Exam	1 [+, +] 2 3 [–,] 4 5 [, +] 6	1 [–, +] 2 3 [–,] 4 5 [+,] 6	1 [+, +] 2 3 [+,] 4 5 [+,] 6	1 [+, –] 2 3 [+, –] 4 6 [+, –] 6	1 [+, –] 2 3 [–,] 4 6 [–, +] 6	1 [+, +] 1 3 [+, –] 3 6 [+, +] 6

Key: government (left sign) · private (right sign)
1, 3, 5 / 2, 4, 6: 1–2 grade 10, 3–4 grade 11, 5–6 grade 12
\+ means boys show higher correlation than girls
– means boys show lower correlation than girls

Table 8.20 Working Memory and Gender
(in sub groups according to school and year)

Interpreting table 8.20 is not easy in that so many variables are involved. However, one key point to note is that, in the national physics examination, boys in government schools consistently show higher correlations compared to girls with most of the variables with most age groups when compared to private schools. Looking at the scientific thinking test, boys in the government schools also frequently show higher correlations than girls with most variables.

The boys in the grade 10 groups tend to show higher correlations when compared to the girls in many areas. This is most noticeable in the scientific thinking test, the physics examination, the biology examination and the mathematics examination.

It is not easy to interpret these observations.

8.12 Some Initial Conclusions

This first experiment attempted to develop a test for scientific thinking and relate its outcomes to outcomes from a test seeking to measure understanding of physics as well as working memory capacity. All the data were related to the national examination data for the three sciences and mathematics.

The 'scientific thinking' test measures something different from other measurements. If this is 'scientific thinking', then it suggests that such thinking is not a part of all the test and examinations surveyed. The physics test seems to measure understanding of ideas rather than recall and this is not the same as 'scientific thinking'.

It is suggested that boys seem to be less willing to memorise than girls and this is often reflected in higher values of correlations because they are relying more on working things out than girls.

While the mean marks in the scientific thinking test are reasonable, this does not provide certain evidence that they are thinking scientifically. Fortunately, two of the items in the test were also used in a previous study and, later, the results here can be compared to those obtained elsewhere.

Along with these measurements, the students also completed a survey and this will be the focus of the next chapter.

Chapter 9

Attitudes

9.1 Self Report Survey

The self-report survey was designed to see how the students saw themselves in the context of learning physics. The aim was to explore if there were areas where their descriptions linked closely to their grasp of scientific thinking. In other words are there specific characteristics or attitudes which are important in being able to think scientifically?

Items were gathered and given to a small number of experienced researchers for comment. After modifications, the test was translated into Arabic and the translation checked. Each part of each question was considered on its own. The questionnaire data were analysed by using SPSS to give the frequencies which selected each option in each question. Correlation was used to explore their responses to any question linked to scores in the scientific thinking test.

It is not possible to measure student attitudes in any absolute way nor is it possible to be certain that they are responding accurately in that they may express views representing how they would like things to be rather than how they are. The data, therefore, have to be interpreted with caution.

The main purpose of the survey was to gain an overall picture of how they see their studies in physics, to see if there are any major trends with age, and to explore any gender differences. Finally, the relationship of their responses to their scores on the Scientific thinking test were considered.

The full questionnaire is shown overleaf.

This survey seeks to find out how you learn Physics.
Your answers will not affect your Physics marks.

Your Name: ....

Name of school: ....

Grade: .... Class ....

If you had to describe "a racing car" you could do it like this:

Quick	✓	☐	☐	☐	☐	☐	Slow
Important	☐	☐	✓	☐	☐	☐	Unimportant
Safe	☐	☐	☐	☐	✓	☐	Dangerous

The positions of the ticks between the word pairs shows that you considered it s very quick, slightly more important than unimportant and quite dangerous.

Use this method of ticking to answer the items 1 and 2

(1) I can learn physics better.....

on my own	☐	☐	☐	☐	☐	☐	in a group
through solving difficult activities	☐	☐	☐	☐	☐	☐	through solving easy activities
through reading physics books	☐	☐	☐	☐	☐	☐	without reading physics books
by doing physics experiments	☐	☐	☐	☐	☐	☐	without doing physics experiments
by relating it to events of daily life	☐	☐	☐	☐	☐	☐	by not relating it to events of daily life

(2) What are your general opinions about your ***physics lessons*** you did last course?

boring	☐	☐	☐	☐	☐	☐	interesting
easy to work out answers	☐	☐	☐	☐	☐	☐	difficult to work out answers
related physics to events of daily life	☐	☐	☐	☐	☐	☐	did not relate physics to events of daily life
made me like physics even more	☐	☐	☐	☐	☐	☐	made me hate science even more
improved my thinking skills	☐	☐	☐	☐	☐	☐	did not improve my thinking skills
enjoyed doing most of them	☐	☐	☐	☐	☐	☐	I hated doing most of them

(3) Think about your studies in physics

I understand things easily	☐	☐	☐	☐	☐	☐	I do not understand things easily
I have a good memory	☐	☐	☐	☐	☐	☐	I do not have a good memory
I learn quickly	☐	☐	☐	☐	☐	☐	I do not learn quickly
I am doing well in my studies	☐	☐	☐	☐	☐	☐	I am not doing well in my studies
I often forget what I learn	☐	☐	☐	☐	☐	☐	I often forget what I learn
I am sure I shall pass my examinations	☐	☐	☐	☐	☐	☐	I am not sure I shall pass my examinations
I feel I can succeed at most things I attempt	☐	☐	☐	☐	☐	☐	I do not feel I can succeed at most things I attempt
I like challenges	☐	☐	☐	☐	☐	☐	I do not like challenges
I enjoy learning in group	☐	☐	☐	☐	☐	☐	I do not enjoy learning in group
I like practical work in physics	☐	☐	☐	☐	☐	☐	I do not like practical work in physics
There is too much mathematics in physics	☐	☐	☐	☐	☐	☐	There is not too much mathematics in physics
My daily life is related to physics studies	☐	☐	☐	☐	☐	☐	My daily life is not related to physics studies
I like to solve problems in physics	☐	☐	☐	☐	☐	☐	I do not like to solve problems in physics
I prefer short answer exam question	☐	☐	☐	☐	☐	☐	I prefer exam question which allow me to express my ideas

Tick the boxes to show your opinions or your answer from question 4 - 5

(4) What are your feelings about working as a group?
(Tick the boxes to shows your opinions)

(a) I found discussions boring	☐	☐	☐	☐	☐
(b) I enjoyed working with members of my group	☐	☐	☐	☐	☐
(c) Most of the ideas from other members of the group were not helpful	☐	☐	☐	☐	☐
(d) Most of the ideas came from one person	☐	☐	☐	☐	☐
(e) Working as a group made it easier for us to get answers	☐	☐	☐	☐	☐
(f) I did not respect ideas from others since they are always wrong	☐	☐	☐	☐	☐

(5) Show your opinion
Tick one box on each line.

(a) I feel I am very good at my studies	☐	☐	☐	☐	☐
(b) I feel that I am just as clever as others my own age	☐	☐	☐	☐	☐
(c) I do not have a good imagination	☐	☐	☐	☐	☐
(d) I take decisions quickly	☐	☐	☐	☐	☐
(e) I am confident that I can finish my studies quickly	☐	☐	☐	☐	☐
(f) I enjoy the challenge of a new problem in my studies	☐	☐	☐	☐	☐
(g) I like to do things in new ways even if I am not sure of the best way	☐	☐	☐	☐	☐

(6) You may have studied topics like:

A Streamline and flow characteristics
B Simple Harmonic Motion
C Refraction of waves
D Electromagnetic waves
E Interference of light
F Diffraction grating
G Geometrical Optics

Put these topics in order showing which you preferred most
Use the letters A to G.

most preferred	☐	☐	☐	☐	☐	☐	☐	*least preferred*

9.2 Data Analysis by Year Group

The data for each year group are now presented as percentages for clarity. The sample sizes are as follows:

Year 10 288 *Year 11* 257 *Year 12* 264

The response patterns for years 10 and 11 are compared using chi-square as a contingency test (see appendix G), frequency data being used for the calculation. Years 11 and 12 are also compared in the same way. Significant values of chi-square are shown in colour, the upper value comparing years 10 and 11 and the lower value comparing years 11 and 12. The data are presented as percentages for clarity.

Question 1

Question 1	***I can learn physics better ....***									
	Year	***Responses (%)***						**$\chi 2$**	**df**	**sig**
on my own ..... in a group	10	13	10	13	16	19	29	3.0	5	n.s.
	11	13	14	12	15	21	25			
	12	14	16	20	19	15	15	3.0	5	n.s.
difficult activities ..... easy activities	10	18	21	20	17	5	19	22.7	5	p<0.001
	11	17	14	20	17	17	16			
	12	11	20	31	20	9	9	24.6	5	p < 0.001
reading .... not reading books	10	35	16	20	10	7	12	21.0	5	p < 0.001
	11	21	20	29	14	9	7			
	12	23	19	24	12	13	9	3.5	5	n.s
with experiments ..... without experiments	10	43	17	16	8	6	11	3.7	5	n.s
	11	43	20	14	9	7	7			
	12	51	22	12	5	5	5	7.0	5	n.s
relating ..... not relating to daily life	10	58	18	9	3	5	7	2.8	5	n.s
	11	56	19	11	5	4	5			
	12	57	18	12	8	3	3	4.0	5	n.s

Table 9.1 Question 1

Views to most questions tend to be quite varied although there is a strong tendency with all groups to see that experimental work is important (perhaps reflecting the lack of enough of it in the Emirates). They also strongly hold the view that they learn physics better when it is related to daily life. This is consistent with the findings of Skryabina (2000) and is an argument for the development of applications-led curricula in physics (Reid, 1999).

There are few significant differences in the views of the different age groups although, looking at the place of difficult activities, year 11 tend to opt for easy activities more than the other two year groups.

Looking at the place of reading books in an educational system where the book defines the material to be memorised, year 10 tends to hold slightly more polarised views, perhaps showing slightly less maturity.

Question 2

Question 2	What are your general opinions about your physics lessons you did last course?									
	Year	Responses (%)						χ2	df	sig
boring .....interesting	10	18	13	20	23	10	16	24.0	5	p < 0.001
	11	33	11	16	13	15	13			
	12	17	14	23	24	17	6	31.5	5	p < 0.001
easy to work out answer.....difficult to	10	14	20	22	23	11	11	3.1	5	n.s
	11	14	20	25	21	13	7			
	12	8	24	25	26	11	7	6.3	5	n.s
related to event of daily life.....do not related	10	17	21	28	18	8	9	1.5	5	n.s
	11	19	23	27	17	8	7			
	12	14	21	29	18	8	12	6.3	5	n.s
made me like physics more.....made me hate	10	31	28	20	10	6	6	2.0	5	n.s
	11	28	24	24	11	7	6			
	12	22	27	25	11	9	8	3.7	5	n.s
improved my thinking skills....did not improve	10	22	20	21	17	9	12	23.3	5	p < 0.001
	11	31	26	24	10	4	5			
	12	12	16	27	22	10	12	52.1	5	p < 0.001
enjoyed doing physics......hated doing physics	10	16	21	28	18	8	9	5.8	5	n.s
	11	20	27	21	16	9	9			
	12	14	18	26	19	13	11	11.2	5	p < 0.05

Table 9.2 Question 2

The general views tend to be positive for all year groups although there is tendency to find all the courses boring. With two questions, there are differences between year groups. Considering the boredom levels of the courses, this varies from year to year. Views are more polarised in year 11, perhaps reflecting their recent course. At this stage, the arts-science divide is more apparent.

Year 11 also differ in how they see their course improving their thinking skills. They are much more positive. It is not obvious why this is so.

Question 3

Question 3		*Think about your studies in physics*								
	Year	*Responses (%)*						$\chi 2$	df	sig
I understand things easily......i do not	10	16	25	22	15	10	14	18.3	5	$p < 0.05$
	11	20	26	30	14	5	6			
	12	10	27	31	14	11	8	16.2	5	$p < 0.001$
I have a good memory...... I do not have	10	13	24	28	19	7	9	8.2	5	n.s
	11	10	30	31	14	9	6			
	12	7	23	28	24	13	6	13.1	5	$p < 0.05$
I learn quickly......I do not learn quickly	10	15	25	24	17	11	8	9.7	5	$p < 0.05$
	11	19	30	26	15	5	5			
	12	10	26	29	23	6	7	13.8	5	$p < 0.05$
I am doing well in my study.....I am not	10	38	29	18	8	2	5	8.0	4	n.s
	11	31	28	18	14	7	3			
	12	30	31	17	12	7	3	0.8	5	n.s
I often forget what I learn.....I often do not	10	10	10	16	22	23	20	31.0	5	$p < 0.001$
	11	18	21	18	15	18	9			
	12	5	17	25	22	20	11	26.0	5	$p < 0.001$
I am sure I shall pass my exam..I am not suer	10	42	23	16	10	3	6	17.6	4	$p < 0.01$
	11	34	20	14	10	13	9			
	12	45	27	14	9	4	2	32.0	5	$p < 0.001$
I can succeed at things I attempt..I do not	10	38	28	21	6	2	5	5.3	4	n.s
	11	45	26	19	5	2	3			
	12	30	32	24	7	5	4	15.6	5	$p < 0.01$
I enjoy learning in group......I do not	10	43	21	14	9	6	7	7.4	5	n.s
	11	34	27	18	10	6	6			
	12	22	19	20	16	13	11	24.5	5	$p < 0.001$
I like practical work in physics....I do not like	10	52	18	14	8	4	5	4.4	5	n.s
	11	45	20	19	8	4	5			
	12	48	22	15	7	4	4	1.4	5	n.s
There is mathematics in physics....there is not	10	56	19	14	5	2	4	8.2	5	n.s
	11	47	25	17	5	4	2			
	12	41	29	17	6	5	3	2.3	5	n.s
Daily life is related to physics.....not related	10	14	15	22	16	13	21	48.2	5	$p < 0.001$
	11	29	26	20	10	9	6			
	12	10	17	24	19	15	15	47.4	5	$p < 0.001$
prefer short answer que....prefer que express ideas	10	41	12	11	12	6	18	25.0	5	$p < 0.001$
	11	24	12	21	15	10	19			
	12	42	13	15	10	7	14	23.0	5	$p < 0.001$

Table 9.3 Question 3

As might be expected, students' views are quite widespread. However, they tend to think they are doing well in their study, being successful, and that they will pass the examination. Practical work is supported (consistent with other studies: see Shah, 2004 for a review) while there is the usual disquiet about mathematics. There are many differences between successive age groups.

In many cases year, 11 is different from the other two years. Thus, year 11 think they learn more quickly, understand things more easily but forget things more easily and are less sure of passing examinations while they are less positive about the use of short answer questions. They also see in a much stronger way that their daily life is much more related to physics. It is possible that, in a three year course in physics, the year 11 group have adjusted to the work but are not yet over-concerned about the final examinations which are over a year away.

Year 12 are more hesitant about groupwork, perhaps the final examination pressure forcing them to work on their own. This might also explain why they say they are less confident about success.

Question 4

Question 4	What are your feeling about working as a group?								
		Responses (%)							
	Year	strongly agree	agree	neutral	disagree	strongly disagree	χ2	df	sig
I found discussions boring	10	8	16	28	29	19	23.0	4	$p < 0.001$
	11	16	16	14	26	28			
	12	6	14	30	34	17	34.5	4	$p < 0.001$
I enjoyed working with members of my group	10	32	43	14	6	5	53.0	4	$p < 0.001$
	11	16	30	21	20	13			
	12	22	45	17	10	7	22.9	4	$p < 0.001$
Most of the ideas from other were not helpful	10	5	9	31	39	16	43.7	4	$p < 0.001$
	11	13	25	21	30	11			
	12	5	9	27	45	15	43.0	4	$p < 0.001$
Most of the ideas came from one person	10	10	19	31	25	14	11.7	4	$p < 0.05$
	11	5	14	33	36	12			
	12	7	20	28	30	15	6.1	4	n.s
Working as a group made it easier for us to get answer	10	52	32	12	2	2	56.9	4	$p < 0.001$
	11	33	25	20	15	8			
	12	39	43	12	4	2	42.0	4	$p < 0.001$
I did not respect ideas from others..cause wrong	10	7	16	38	24	15	41.4	4	$p < 0.001$
	11	26	19	28	16	13			
	12	5	16	39	25	15	48.1	4	$p < 0.001$

Table 9.4 Question 4

Their views relating to group work tend to be fairly positive in all questions although it has to be recognised that their experience of learning in this way is limited and the views expressed may be aspiration rather than reality. There are many differences between age groups, reflecting maturational development.

Question 5

Question 5	Show your opinion								
		Responses (%)							
	Year	strongly agree	agree	neutral	disagree	strongly disagree	χ2	df	sig
I feel I am very good at my studies	10	22	38	26	9	5	12.6	3	0.01
	11	24	49	19	6	2			
	12	11	49	22	11	6	20.8	3	0.001
I feel that I am just as clever as others my own age	10	18	39	31	9	3	2.5	3	n.s.
	11	23	39	26	9	3			
	12	16	36	33	11	4	16.8	3	0.001
I do not have a good imagination	10	14	21	30	26	10	5.2	4	n.s.
	11	12	25	35	19	9			
	12	13	27	26	20	14	7.8	4	n.s.
I take decisions quickly	10	13	31	32	20	4	1.2	3	n.s.
	11	14	33	28	20	4			
	12	12	33	32	19	5	1.5	3	n.s
I am confident that I can finish my studies quickly	10	33	32	17	13	6	1.8	4	n.s.
	11	38	31	16	10	5			
	12	27	39	18	11	5	6.9	4	n.s.
I en joy the challenge of a new problem in my studies	10	16	29	21	24	10	4.1	4	n.s.
	11	15	25	23	23	15			
	12	20	28	20	23	9	7.5	4	n.s.
I like to do things in new ways even if not sure of the best way	10	29	34	15	15	8	1.3	4	n.s.
	11	25	37	16	14	9			
	12	21	33	20	15	11	3.7	4	n.s.

Table 9.5 Question 5

The responses present a fairly positive picture and there are few differences between the three age groups. The main area where differences are observed is that grade 11 are more confident in their studies but this increased confidence seems to have gone by grade 12.

Question 6

Question 6 asked the students to place various topics in order of preference. The topics for each year group were different. The topics were labelled from A to G.

N = 288	Most preferred						Least preferred
%	A	B	C	D	E	F	G
Elasticity	24	15	12	5	7	21	17
Hooke's Law	15	12	20	9	7	19	19
Surface Tension	23	15	16	13	13	12	9
Fluid Pressure	11	22	14	18	14	13	8
Archimedes Principle	9	12	20	17	15	12	15
Work	10	13	10	18	18	16	16
Energy	7	12	9	20	27	9	16

Table 9.6 Question 6 (Year 10)

From this table, it can be seen that there is considerable polarisation of views about elasticity and Hooke's Law - many are very positive or very negative. It is also can be observed that there is not any topic which shows very high levels of popularity or, indeed, very low levels of popularity. Nonetheless, least liked by the students are: energy, Archimedes, work while most popular are: elasticity (but views are polarised) and surface tension. Al-Hail (2005) found out in Qatar that the students in the first year (age 16) had problems understanding topics like matter and its mechanical characteristics (fluid pressure and Archimedes' principle) and energy although only 7 out of 202 students claimed that surface tension is difficult to understand.

N = 257	*Most preferred*						*Least preferred*
%	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Vectors	28	23	24	18	7	7	5
Linear motion	24	16	26	16	14	8	7
Newton's Laws	17	16	18	16	12	18	10
Gravitational Forces	14	15	12	15	16	15	14
Friction	9	13	8	16	23	18	15
Moments of Force	4	10	8	12	14	23	18
Circular motion	4	7	5	8	13	12	30

Table 9.7 Question 6 (Year 11)

Year 11 does not show polarised views on any topic. Most popular are vectors, linear motion, Newton's law, gravitational force and least popular are friction, moments of force and circular motion. While the concept of force is one of the most fundamental in physics, it is also widely misunderstood with Johns and Mooney (1981, p. 356) noting that, "*many students are unable to place the concepts in perspective. The result of this difficulty is that the students' knowledge and understanding of physics is frequently fragmented and compartmentalised and they never perceive a unity of the subject*". Friction illustrates the difficulty in that it cannot be seen and students just can observe it by imagination, although they do the experiment. By contrast, vectors is liked by the students, perhaps because it is capable of being mastered on paper by following sets of prescribed procedures. Interpretation and application of vector ideas in real situations is, however, much more complex but this is not studied at this age.

Al-Hail (2005) also found that students in the second year classified Newton's Laws as difficult and that they had problems to sketch the force of friction onto the diagrams. They found it very difficult to pick out information from the diagrams. Paulo and Adriano (2005) also observed from there studies that ther is a lack of understanding of frictional force with students in Portugal.

N = 264	*Most preferred*						*Least preferred*
%	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Streamline and flow	45	14	9	7	7	7	8
Simple Harmonic Motion	19	29	18	9	8	7	11
Refraction of waves	15	29	24	14	9	8	3
Electromagnetic waves	8	12	20	20	21	10	9
Interference of light	4	8	15	21	23	15	14
Diffraction grating	2	4	6	15	18	29	27
Geometrical Optics	6	6	10	12	15	22	29

Table 9.8 Question 6 (Year 12)

This table also shows that there are no polarised views with year 12. Strangely, popularity of topics falls consistently descending the list. Topics like electromagnetic waves, interference, diffraction gratings, and geometrical options are often found to be very difficult for students (see Zapiti, 1999). Much is intangible and requires some grasp of the concept of wave motion.

9.3 Conclusions

The general pattern shows that they strongly want physics to be related to life but their courses do not emphasise this strongly, the course being not too exciting. Practical work and group working are both favoured although they lack experience of the latter. They express reasonable confidence and general security in their learning, perhaps reflecting the security in knowledge memorised and then tested in short questions.

The topics which are least liked included energy and work, Archimedes' Principle; friction, moments of force, and circular motion; interference, diffraction and geometrical optics. Many of these topics are also noted to be difficult in the review by Zapiti (1999).

9.4 Gender Comparisons

It is possible to compare the responses of the boys and the girls to the questions. Taking each year group on its own gives rather small samples and, therefore, all three year groups were added together to give an overall picture of how the boys and girls differed in their views. This gave 364 boys and 445 girls. As before, chi-square as contingency test was used.

Question 1	*I can Learn Physics better ....*									
Grade	***10***	***Responses (%)***						**χ2**	**df**	**sig**
on my own ..... in a group	girls	12	14	16	18	16	24	10.2	5	n.s.
	boys	16	12	13	14	22	23			
difficult activities ..... easy activities	girls	16	18	24	20	8	14	8.2	5	n.s.
	boys	16	22	29	18	6	10			
reading .... not reading books	girls	26	17	23	11	11	11	6.0	5	n.s.
	boys	31	19	22	11	8	8			
with ..... without experiments	girls	52	18	12	6	5	7	10.3	5	n.s.
	boys	41	22	15	8	6	8			
relating ..... not relating to daily life	girls	64	18	9	4	2	3	17.6	4	p < 0.01
	boys	54	18	10	6	5	7			

Table 9.9 Question 1 (boys and girls)

There are few differences in the views of boys and girls when thinking about learning physics. However, girls strongly prefer that their work in physics is related to life and this is consistent with the findings of Skryabina (Reid and Skryabina and Reid, 2002a).

Question 2	***What are general opinons about your physics lessons***									
Grade	***10***	***Responses (%)***						**χ2**	**df**	**sig**
boring ..... interesting	girls	16	12	23	21	16	12	3.1	5	n.s.
	boys	16	11	20	25	14	14			
easy to work out answer.....difficult to	girls	10	25	23	25	10	7	9.4	5	n.s.
	boys	13	18	##	21	13	9			
related to event of daily life.....do not related	girls	18	23	28	16	7	9	5.3	5	n.s.
	boys	15	23	25	18	9	10			
made me like physics more.....made me hate	girls	31	25	22	9	8	6	7.3	4	n.s.
	boys	27	27	26	11	4	5			
improved my thinking skills....did not improve	girls	19	19	24	18	8	12	3.8	5	n.s.
	boys	19	23	23	16	10	9			
enjoyed ... hated doing most of them	girls	18	21	22	19	9	11	13.4	5	p < 0.05
	boys	17	22	32	14	8	7			

Table 9.10 Question 2 (boys and girls)

There are few differences in the views of boys and girls when thinking about physics lessons. Boys are marginally enjoying the lessons more.

Question 3	*Think about your studies in physics*									
Grade	***10***	***Responses (%)***						**χ2**	**df**	**sig**
I understand things easily......i do not	girls	16	25	26	15	8	11	11.5	5	$p < 0.05$
	boys	12	30	28	11	11	8			
I have a good memory...... I do not have	girls	8	22	29	22	11	7	22.9	5	$p < 0.001$
	boys	15	30	28	16	6	5			
I learn quickly......I do not learn quickly	girls	14	26	25	20	8	7	3.1	5	n.s.
	boys	14	31	25	19	7	5			
I am doing well in my study.....I am not	girls	35	26	17	12	6	4	7.7	4	n.s.
	boys	38	31	17	7	5	3			
I often forget what I learn.....I often do not	girls	6	14	20	22	22	15	5.9	5	n.s.
	boys	9	14	20	17	23	18			
I am sure I shall pass my exam..I am not suer	girls	42	23	15	12	5	4	16.0	4	$p < 0.01$
	boys	51	24	15	5	2	4			
I can succeed at things I attempt..I do not	girls	34	29	22	8	3	5	9.8	3	$p < 0.05$
	boys	38	34	19	5	2	3			
I enjoy learning in group......I do not	girls	32	18	16	14	10	9	10.6	5	n.s.
	boys	34	21	21	9	7	9			
I like practical work in physics....I do not like	girls	50	21	15	7	4	3	2.0	4	n.s.
	boys	52	18	16	7	3	5			
There is too much mathematics in physics....th	girls	52	25	14	5	3	2	11.5	4	$p < 0.05$
	boys	41	28	17	6	5	4			
Daily life is related to physics.....not related	girls	13	18	21	18	14	16	7.1	5	n.s.
	boys	12	15	29	15	13	15			
prefer short answer que....prefer que express ideas	girls	38	10	12	12	7	21	10.6	5	n.s.
	boys	40	16	12	10	8	14			

Table 9.11 Question 3 (boys and girls)

There are no differences in the views of boys and girls when thinking about their studies in physics in seven of the twelve questions. However, boys think they have better memories although this is likely to be over-confidence! This confidence is seen in their view that they will pass their examinations and their slightly greater confidence in being successful. Girls are slightly less happy than boys about the mathematical elements in physics.

Question 4		What are your feeling about working as a group?							
		Responses (%)							
grade	***10***	strongly agree	agree	neutral	disagree	strongly	χ2	df	sig
I found discussions boring	girls	7	14	26	33	20	1.2	4	n.s.
	boys	5	15	25	34	19			
I enjoyed working with members of my group	girls	25	44	17	7	7	3.2	3	n.s.
	boys	29	45	14	9	3			
Most of the ideas from other were not helpful	girls	4	9	27	44	17	4.3	4	n.s.
	boys	5	10	32	38	16			
Most of the ideas came from one person	girls	8	22	31	29	11	14.2	4	$p < 0.01$
	boys	8	15	30	30	18			
Working as a group made it easier for us to get answers	girls	46	37	11	4	3	2.2	3	n.s.
	boys	50	34	11	3	2			
I did not respect ideas from others.....cause wrong	girls	5	14	41	26	14	4.6	4	n.s.
	boys	7	15	36	25	18			

Table 9.12 Question 4 (boys and girls)

There are almost no differences in table 9.12, with boys being slightly more of the view that ideas in a group discussion tend not to come just from one person. This may simply reflect differential social maturity at this age.

Question 5		Show your opinion							
		Responses (%)							
Grade	***10***	strongly agree	agree	neutral	disagree	strongly	χ2	df	sig
I feel I am very good at my studies	girls	18	42	24	11	5	11.3	3	$p < 0.01$
	boys	21	50	20	6	3			
I feel that I am just as clever as others my own age	girls	17	35	32	12	4	15.7	3	$p < 0.01$
	boys	22	42	28	6	2			
I d not have a good imagination	girls	12	25	28	24	11	5.3	4	n.s.
	boys	14	24	33	18	12			
I take decisions quickly	girls	12	33	31	21	4	1.7	3	n.s.
	boys	15	32	31	18	5			
I am confident that I can finish my studies quickly	girls	31	33	18	12	6	2.7	3	n.s.
	boys	35	34	17	10	4			
I enjoy the challenge of a new problem in my studies	girls	19	26	20	25	9	8.9	4	n.s.
	boys	14	28	23	21	14			
I like to do things in new ways even if not sure of the best way	girls	26	35	15	15	9	4.1	4	n.s.
	boys	25	33	20	13	9			

Table 9.13 Question 5 (boys and girls)

Again, there are few differences between girls and boys. However, boys are more confident (over confident?) of being good at their studies as well as being as clever as others of their own age. This simply reflects the different levels of maturity of boys and girls at these ages as well as the tendency of girls to be less confident (and maybe more realistic).

Question 6		**Put these topics in order showing which you preferred most**									
N(girls) = 158; N(boys) = 130		*Most preferred*						*Least preferred*			
Grade	***10***	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**$\chi 2$**	**df**	**sig**
Elasticity	girls	22	17	14	3	6	22	17	6.2	6	n.s.
	boys	27	12	9	6	9	19	18			
Hooke's Law	girls	16	8	25	8	4	21	19	12.8	5	$p < 0.05$
	boys	13	18	14	9	9	17	20			
Surface Tension	girls	24	17	13	10	11	15	11	10.0	6	n.s.
	boys	22	14	20	15	16	8	7			
Fluid Pressure	girls	12	20	13	15	15	14	11	7.4	5	n.s.
	boys	10	23	15	23	12	12	4			
Archimedes Principle	girls	7	15	17	20	14	13	15	9.0	6	n.s.
	boys	12	8	24	15	16	11	15			
Work	girls	11	12	11	22	19	12	13	8.5	6	n.s.
	boys	9	13	9	14	16	20	19			
Energy	girls	8	11	9	22	32	4	14	9.8	5	n.s.
	boys	7	13	9	18	22	15	18			

Table 9.14 Question 6 (year 10, boys and girls)

It is clear from the table that there are almost no significant differences between girls and boys. With Hooke's Law, it seems that boys prefer more than girls but the pattern of responses is not clear cut. It is interesting to note the lack of gender difference, suggesting that physics should be equally attractive to both genders.

Question 6		**Put these topics in order showing which you preferred most**									
N(girls) = 141; N(boys) = 116		*Most preferred*						*Least preferred*			
Grade	***11***	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**$\chi 2$**	**df**	**sig**
Vectors	girls	27	9	33	6	11	9	6	14.1	3	$p < 0.01$
	boys	39	13	33	3	4	5	1			
Linear motion	girls	20	16	28	9	16	8	4	7.9	6	n.s.
	boys	15	23	24	14	9	11	5			
Newton's Laws	girls	15	21	15	15	9	17	9	7.7	6	n.s.
	boys	9	22	16	15	19	12	6			
Gravitational Forces	girls	16	18	10	18	18	12	6	7.0	6	n.s.
	boys	12	15	10	15	18	24	6			
Friction	girls	6	16	6	25	17	17	14	1.0	6	n.s.
	boys	9	10	6	30	20	16	13			
Moments of Force	girls	8	12	4	18	14	26	19	5.6	6	n.s.
	boys	8	12	5	15	19	17	27			
Circular motion	girls	8	8	4	9	16	11	43	2.2	6	n.s.
	boys	7	5	6	9	12	15	43			

Table 9.15 Question 6 (year 11, boys and girls)

Again, there is only one significant difference between girls and boys. The lack of difference is again interesting.

Question 6		**Put these topics in order showing which you preferred most**									
N(girls) = 146; N(boys) = 112		*Most preferred*						*Least preferred*			
Grade	***12***	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**$\chi 2$**	**df**	**sig**
Streamline and flow	girls	49	18	17	3	3	3	6	12.6	5	$p < 0.05$
	boys	40	21	13	13	5	1	7			
Simple Harmonic Motion	girls	16	26	32	10	4	5	8	5.7	4	n.s.
	boys	11	30	24	14	14	4	5			
Refraction of waves	girls	11	20	25	19	16	5	8	5.2	6	n.s.
	boys	8	14	21	22	13	7	13			
Electromagnetic waves	girls	4	9	14	24	21	14	12	7.1	5	n.s.
	boys	13	10	13	13	21	16	12			
Interference of light	girls	8	9	6	26	22	14	18	14.2	6	$p < 0.05$
	boys	7	6	13	16	24	23	10			
Diffraction grating	girls	6	8	5	10	18	30	23	6.7	5	n.s.
	boys	11	7	12	12	12	27	22			
Geometrical Optics	girls	6	11	2	10	16	30	25	14.3	6	$p < 0.05$
	boys	11	12	4	9	11	22	31			

Table 9.16 Question 6 (year 12, boys and girls)

In three areas, there appear to be gender differences although the patterns of responses do not make it easy to say which gender has a preference greater than the other. Possibly, girls have a higher preference for streamline and flow with boys have a higher preference for interference and geometrical optics. However, the lack of clear cut differences overall is the most interesting feature.

9.5 Conclusion

The remarkable overall observation is the lack of differences observed between the responses of the boys and the girls. This is consistent with the general findings from Reid and Skryabina (2003). On this basis, physics should be equally attractive to boys and girls.

9.6 Relationship Between the Survey and Other Measurements

The student responses to the questionnaire items (questions 1 to 5, question 6 is not open to this analysis) were correlated using Kendall's Tau-b (see appendix G) with their measured working memory capacity, their performance in the physics understanding test and their performance in the scientific thinking test. 36 correlation coefficients were obtained for each comparison and none exceed a numerical value of 0.1. This indicates that students' perceptions relating to their learning in physics are not related in any substantial way to either their working memory capacity or their skills in understanding and applying physics. Of course, the test for the latter aimed not to make any excessive demand on working memory and lack of correlations may simply reflect the structure of the test.

Of greater interest in this study is the lack of correlation between the outcomes for the scientific thinking test and the students' perception relating to their learning in physics. Assuming that the scientific thinking test is valid, this means that it is unlikely that it is possible to gain any estimate of skills in scientific thinking using survey approaches. This is consistent with the findings of Hindal (2007) where she found that surveys did not relate to actual measurements of a range of cognitive skills and characteristics.

By contrast, when the student responses to the questionnaire items (questions 1 to 5) were correlated with their performance in the national physics examination, some larger correlations were obtained although most of the survey items showed no significant correlations. The following items gave correlations greater than 0.1 with the national physics examination scores, the questions being shown polarised to give a positive correlation.

(1)	I can learn physics better	
(d)	with doing physics experiments	0.12 ($p < 0.01$)
(3)	Think about your studies in physics	
(b)	I do not have a good memory	0.11 ($p < 0.01$
(g)	I do not feel I can succeed at most things I attempt	0.46 ($p < 0.001$)
(h)	I enjoy studying physics	0.12 ($p < 001$)
(l)	I prefer exam questions which allow me to expand my ideas	0.16 ($p < 0.001$)
(4)	What are your feeling about working as a group?	
(a)	I found discussions boring	0.20 ($p < 0001$)
(b)	I do not enjoy working with members of my group	0.16 ($p < 0.001$)
(d)	Most of the ideas do not come from one person	0.20 ($p < 0.001$)
(f)	I respect ideas from others	0.12 ($p < 0.01$)
(5)	Show your opinion	
(f)	I feel confident that I shall finish my studies	0.27 ($p < 0.001$)

It is difficult to draw any clear cut conclusions from these results. However, it is remarkable that those who do not feel they can succeed at most things they attempt are those who do best in the national examinations.

9.7 Overall Summary

Chapter eight outlined the development and use of a test of scientific thinking and the relationship of the results from that test to other tests. It was found that the test of scientific thinking measured something very different from recall and understanding. Chapter nine showed that the students strongly wished that their studies in physics were related to life but there appeared to be some uncertainty relating to assessment. Of importance is the attempt to relate their perception of their learning in physics (the theme of chapter nine) to their performance in a test of scientific thinking (the theme in chapter eight. This showed that there were very few relationships. Thus, how they viewed a wide range of aspects of their learning in physics seemed to be largely unrelated to any skills which could be described as scientific thinking.

The next issue to be explored is whether scientific thinking can be enhanced by means of focussed teaching.

Chapter 10

Can Scientific Thinking be Taught

10.1 Introduction

While the importance of developing scientific thinking skills is considerable, the accurate description of such skills and their measurement is much more difficult. The purpose of the work described in the last two chapters was to attempt to see what is happening at ages (16-18) in schools in the United Arab Emirates in relation to a range of skills including scientific thinking. This involved the develop and use of a test of scientific thinking (set in the context of physics), a test seeking to measure understanding in relation to topics taught in physics, an analysis of available national examination data; a measurement of working memory capacity.

It was found that the test of scientific thinking was measuring something very different when compared to the test of understanding physics and the national examinations. Students performed reasonably well in the test of scientific thinking, suggesting that this skill is present to some extent. Their performance in the test improved with age, suggesting that the skills involved are gained either with age or with more experience in the sciences.

In the light of this, the next stage is to attempt to see if scientific thinking skills can be taught. In addition, data from previous research was used to gain some insight into whether the students were actually thinking scientifically.

10.2 The Approach Adopted

The first step was to develop a set of teaching units which could be used with students in Grades 10, 11 and 12. These units were designed to develop the skills which had been found from the analysis of scientific thinking in chapter 7. The units were used with samples of students in years 10, 11 and 12 and, at the end, their performance in the scientific thinking test used previously was measured. Their performance in this test was then compared to the performance in the same test of the previous students who had *not* undertaken any teaching units, the data from chapter 8. The students also undertook a new test of physics understanding and applications as well as having their working memory capacity measured using the digit span backwards test.

Students using Teaching Units		Students not using Teaching Units	
Year 10	198	Year 10	288
Year 11	209	Year 11	257
Year 12	196	Year 12	264
TOTAL	**603**	**TOTAL**	**809**

Table 10.1 Samples Used

10.3 The Units

Before the units were developed, the key features of scientific thinking were analysed in order to give a description of the skills which were to be developed. The units had to be used with three year groups. Therefore, they had to depend on the physics ideas which were known to the youngest group. However, they were deliberately designed to offer challenges to all age groups while not depending on ideas only known to the older groups. The plan is shown in table 10.2.

	Unit	Description
1	A Question of Temperature:	How some experimental data can be interpreted
2	A Hot Mystery:	This looks at the way data can be interpreted in relation to specific heat capacity
3	The Puzzle of Electricity:	How can experiments be devised to show some basic ideas in electricity
4	Water - A Unique Substance:	Heat and temperature, devising an experiment to test an hypothesis
5	The Big Challenge:	How to invent an apparatus to 'weigh' atoms. (devising an experiment)

Table 10.2 Units Developed

The units were *not* designed to teach physics but to seek to allow pupils to think about the nature and place of experimentation in relation to the development of ideas in physics. They all involved students working in small groups of three or four. The production of 'right' answers was not seen as important as the discussion of ideas leading to 'possible' answers. The key feature was their attempt to illustrate and apply the key ideas of scientific thinking in an explicit way. The units need to be seen as a set which, together, seek to develop the key skills identified as critical in scientific thinking. Another feature of the units was that they were deliberately set in a 'friendly' style. This was done in order to provoke discussion and the free exchange of ideas and approaches, without fear of being penalised in any way in their studies.

After the units had been written, they were given to experienced teachers of physics for criticism and comment and they were then adjusted in the light of the comments. They were the translated into Arabic and the translation checked. The complete units are shown in appendix E. However, samples of parts of some of the them are shown below.

Sample of Unit (1)

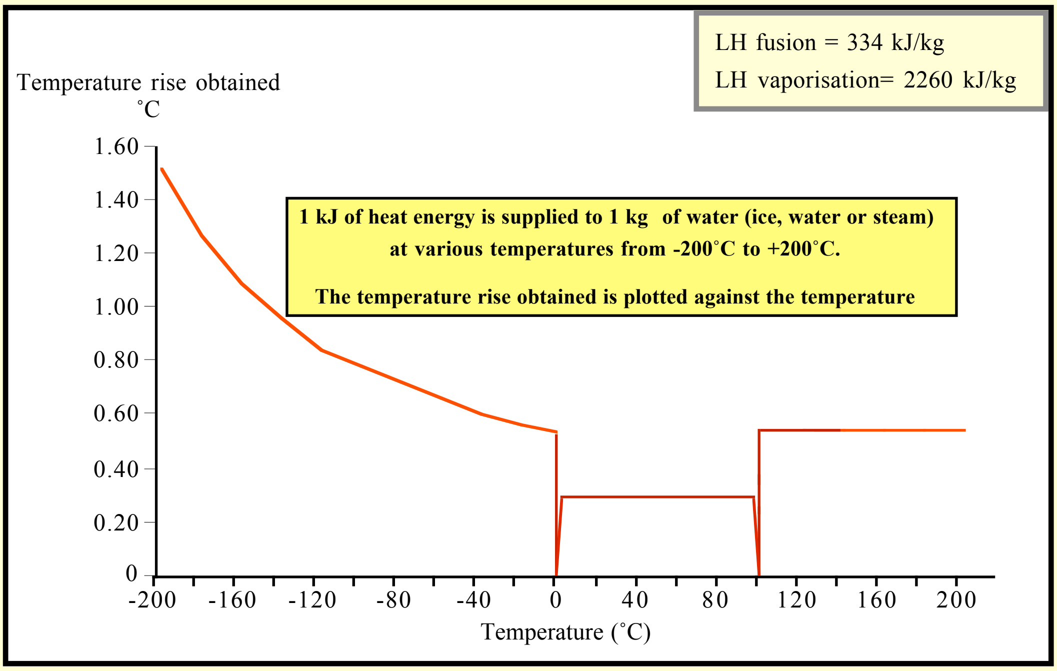
Aim of Unit: Interpretation of experimental data ot draw valid conclusions

In this experiment, some students carefully heated a block of ice, of mass 1g, from -200˚C until it melted and then on until it boiled and then on to a temperature of +200˚C. The pressure was constant at one atmosphere.

They found that, for every Joule of Heat Energy supplied, the temperature did not rise at a steady rate:

At -200˚C	1 Joule of Heat Energy raised the temperature by nearly 1.5˚C.
At 160˚C	1 Joule of Heat Energy raised the temperature by 0.5˚C.
At 60˚C	1 Joule of Heat Energy raised the temperature only by 0.25˚C.
At 0˚C	1 Joule of Heat Energy did not raise the temperature at all.
At 100˚C	1 Joule of Heat Energy did not raise the temperature at all.

They plotted their results and this is what they obtained:



Working as a group, discuss the following questions.

(1) Why does the line of the graph drop to zero for the temperature rise obtained at 0˚C and 100˚C.

(2) Offer some explanation why the line is lower between 0˚C and 100˚C (when the the water is in liquid form) than when less than 0˚C and when greater than 100˚C.

(3) Can you think of any reason why the line is a falling curve when the water is in the form of ice but is a straight line when the water is in the form of steam?

Sample of Unit (2)

Aim of unit: This looks at the way data can be interpreted in relation to specific heat capacity, the emphasis being on data choice, pattern seeking,

A Hot Mystery

You will be working in a group of three.
Discuss answers to the questions below.
One of you can write down your agreed answers.

Part 1

The specific heat capacities of metals vary.

Here are some values:

Element	Spec Heat J/g/K
Aluminium	0.900
Copper	0.385
Gold	0.130
Iron	0.444
Lead	0.134
Magnesium	1.017
Silver	0.238
Tin	0.222
Zinc	0.389

Look at the table of values.
You are looking for any kind of pattern:
For example, aluminium has a much higher specific heat than, say, gold.
Magnesium is somewhat similar to aluminium while lead is nearer gold.

Can you see any pattern for all the values?

Write down the possible pattern you can see:

....
....
....

Do NOT turn over until told to do so

Sample of Unit (3)

Aim of Unit: The focus here is on devising of appropriate experiments

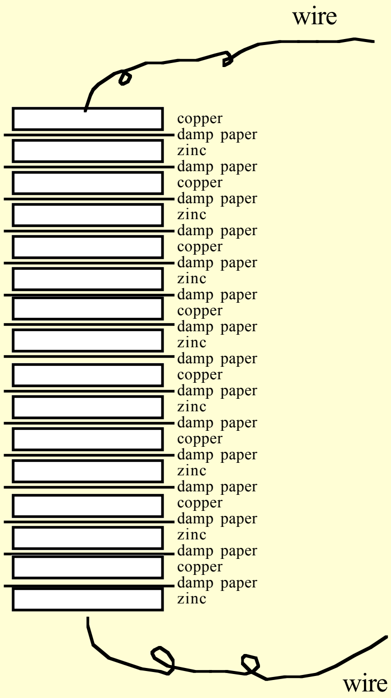
The Puzzle of Electricity

You will be working in a group of three.
Discuss answers to the questions below.
One of you can write down your agreed answers.

You may have seen sparks with electricity and thought of this in terms of electrical charge jumping across an air gap.

You may have seen a Van de Graaf generator and seen hair standing up on end. Perhaps you saw this as electrical charges repelling each other.

Just over 200 years ago, little was known about electrical charge. One day, an Italian called Volta built a simple primitive battery. It looked at bit like this:



Imagine you lived in Volta's time.

Remember: no one really understood much about charge or electricity.

The unit goes on to explore how the two wires seemed to behave differently in their effects on things around and how this led to the ideas of positive and negative charge.

Sample of Unit (4)

Aim of Unit: Based on the theme of heat and temperature, devising an experiment to test an hypothesis is the central idea.

Water - a Unique Substance

Look at the questions below and try to answer them on your own.

Part 1

(1) Pure water has a specific heat capacity of 4.18 $kJkg^{-1}K^{-1}$.
Iron of a certain quality has a specific heat capacity of 0.418 $kJkg^{-1}K^{-1}$.
The latent heat of fusion of ice is 334 $kJkg^{-1}$.
The latent heat of vaporisation of water is 2260 $kJkg^{-1}$.

Look at the table below and answer the questions which follow, using the letters provided.
You may use any box as often as you wish.

50g pure water heated from 0˚C to 50˚C **A**	100g pure ice melting completely at a constant temperature **B**	500g iron heated from 0˚C to 50˚C **C**
200g pure ice melting completely at a constant temperature **E**	100g pure water freezing to ice at a constant temperature **F**	50g iron heated from 0˚C to 50˚C **G**
500g pure water heated from 0˚C to 50˚C **H**	100g pure water boiling completely to steam at a constant temperature **I**	5000g iron heated from 0˚C to 50˚C **J**
50g pure water heated from 25˚C to 75˚C **K**	500g iron heated from 25˚C to 75˚C **L**	500g pure water cooled from 50˚C to 0˚C **M**

Select ***all*** the boxes which:

(a) Take place at the same temperature as box B.
....

(b) Involve the same energy change as box A.
....

(c) Involve the same energy change as box H.
....

(d) Involve the highest energy change.
....

(e) Involve the lowest temperature at the end.
....

Now compare your answers with other students in your group.
Discuss any differences you have found.

Sample of Unit (5)

Aim: The focus here was the development of apparatus to 'weigh' atoms, seen as part of the skill of devising an experiment.

The Big Challenge

Design and Experiment to Weigh Atoms !!

Sounds Impossible ??

Let's start at the beginning

You will be working in a group of three.
Discuss answers to the questions below.
One of you can write down your agreed answers.

<u>Part 1</u>

First Thoughts

What do you think atoms will weigh - just approximately?
Discuss this in your group

Have a guess:
Tick one box

☐	Roughly	10^{-3}g	(milligrams)
☐	Roughly	10^{-6}g	(micrograms)
☐	Roughly	10^{-9}g	(nanograms)
☐	Roughly	10^{-12}g	(picograms)
☐	Roughly	10^{-18}g	(attograms)
☐	Roughly	10^{-24}g	

How can we find out?

Here is one piece of information: in 5 cm^3 water (a teaspoonful), there are approximately 5 x 10^{23} atoms in the water molecules.

Use this information to estimate the kind of weight atoms might have

When you discuss this, tick your agreed choice:

10^{-3}g 10^{-6}g 10^{-9}g 10^{-12}g 10^{-18}g 10^{-24}g 10^{-30}g

There was a set of teacher's guides and these are shown in full.

Physics Thinking Units

Teacher's Guide

There are five units in this set. Their titles are:

(1)	*A Question of Temperature*	How some experimental data can be interpreted
(2)	*A Hot Mystery*	This looks at the way data can be interpreted in relation to specific heat capacity
(3)	*The Puzzle of Electricity*	How can experiments be devised to show some basic ideas in electricity
(4)	*Water - A Unique Substance*	Heat and temperature. devising an experiment
(5)	*The Big Challenge*	How to invent an apparatus to 'weigh' atoms.

The units are not designed to teach Physics but seek to allow pupils to think about the nature and place of experimentation in relation to the development of ideas in Physics.

They all involve pupils working in small groups of three. When using any of these units, form your class into groups of three (an occasional four is fine if numbers are not a multiple of three). Allow the groups to work at the problems *on their own*. Do not intervene unless a group is completely stuck and, then, only offer some hints to re-start them. The production of 'right' answers is not as important as the discussion of ideas leading to 'possible' answers.

(1) ***A Question of Temperature***

(a) Form groups of three
(b) Give out a copy of the unit to each pupil
(c) Encourage them to talk to each other and not to try to work individually.
(d) Likely answers:

Question (1) They should come with ideas related to latent heat.

Question (2) The lower line means that more heat energy is need for each degree rise in temperature. This is because during the water phase, links between molecules (hydrogen bonds) are being broken. Liquid has a fantastic thermal capacity because of this.

Question (3) In steam, the water molecules are far apart in space and heat energy merely increases kinetic energy. In the ice phase, the heat energy is going in to vibrational energy and this varies as the temperature rises.

(2) ***A Hot Mystery***

(a) Form groups of three
(b) Give out a copy of the unit to each pupil
(c) Encourage them to talk to each other and not to try to work individually.
(d) Likely answers:

Part 1 Some kind of idea about specific heat capacities falling with the 'heavier' metals.

Part 2 The same pattern seems to hold true but they need data for more substances.

Part 3 The pattern still seems to hold. to check more quantitatively, they could look at mass of atoms, atomic number, density, size of atoms.

Part 4 Given this data, the pattern may still be true but it is very difficult to be sure.
The key idea is to spot: if the specific heat capacity falls with increases in any of the four characteristics, then multiplying the specific heat capacity by the characteristic might give a constant (like PV is a constant if T is fixed).

Part 5 Given this 'multiplied' data, it is easy to see that density and radius are not really the right factors. Atomic mass looks best but atomic number is also possible.

(3) ***The Puzzle of Electricity***

(a) Form groups of three
(b) Give out a copy of the unit to each pupil
(c) Encourage them to talk to each other and not to try to work individually.
(d) Likely answers:

Page 2 (a) Many possibilities. For example, a bulb between the two wires might light but one between the top wire of *two* batteries would not. Either wire would cause an electroscope to diverge and the use of the second wire would reverse the effect and then cause it to diverge again. If the two wires were dipped into salt water, the smell of chlorine would be found at the wire connected to the copper only.

Page 2 (b) There is no meaning to the words ‘positive’ and ‘negative’. They are merely *descriptions* of opposites. No experiment can show anything about this except that there are *two* effects which are *opposite in some way*.

Page 3 This is really open-ended! They might use two electroscopes and show they discharge each other. They might look for magnetic effects, electrolysis. It is incredibly difficult to show that the negative move easily. The problem is that electrons moving in one direction behaves just like some kind of positive charge moving in the opposite direction! It is possible to look at the speeds of movement of beams of positive and negative charges in vacuum tubes and the relative way of generating the movement which reflects mass/charge ratios.

(4) Water - A Unique Substance

(a) Give out a copy of the unit to each pupil
(b) Part 1 is to be done individually and then form groups of three to compare results.
(c) Encourage them to talk to each other and not to try to work individually.
(d) Answers:

Part 1 (a) E, F (b) C, K, L (c) J, M (d) I (e) B, E, F, M

Part 2 (a) The cold feeling is related to the rate of heat transfer form the hand to the colder material. Iron conducts heat energy faster but, on touching ice, it can melt, absorbing a huge amount of energy to overcome the latent heat.

(b) Iron has a much lower specific heat capacity compared to water. Therefore, less heat energy is stored in iron.

(c) 1.37×10^{15} Kg Heat Energy stored = 2.86×10^{15}

Part 3 (d) The original ways depend on measuring the temperature rise at top and bottom of waterfalls but the rise is very very low.
It is also possible to take a cylinder of water containing pieces of rock and rotate the cylinder for a long tim, measuring the temperature of the water before and after, relating the input mechanical energy to the temperature rise. Calculation will show how small the temperature rise will be.

(5) ***The Big Challenge***

(a) Form groups of three
(b) Give out a copy of the unit to each pupil
(c) Encourage them to talk to each other and not to try to work individually.
(d) Likely answers:

Part 1 Their first guess may be anything but the second estimate should come nearer to 10^{-24} g
Part 2 They should come up with about 3 or 4 equations.
Part 3 Getting atoms all to move in one direction. It might seem easy to think in terms of rapid flow through a narrow jet. Probably, they will not think of an accelerated beam of charged particles.
Part 4 They might come up with altering the ‘negativeness’ om the charged plate but it still leaves it uncertain how they can measure velocity.
Part 5 They may well think of deflection in electrical or magnetic fields.
Part 6 They should come up with simple deflection in the diagram
Part 7 If they can think in terms of two particles of different mass, then the extent of deflection will vary.
Part 8 This offers the answers in terms of the *principles* involved in the mass spectrometer.
Problems: two major ones: how do we ensure singly charge particles always? There is no absolute mass, no scale on the detector. So it has to be *relative* mass.

10.4 Outcomes from Scientific Thinking Test

The scientific thinking test described in chapter 8 was used again with all three age groups shortly after they had completed the units. Histograms showing that the distributions of marks are very close to normal are shown in figure 10.1.

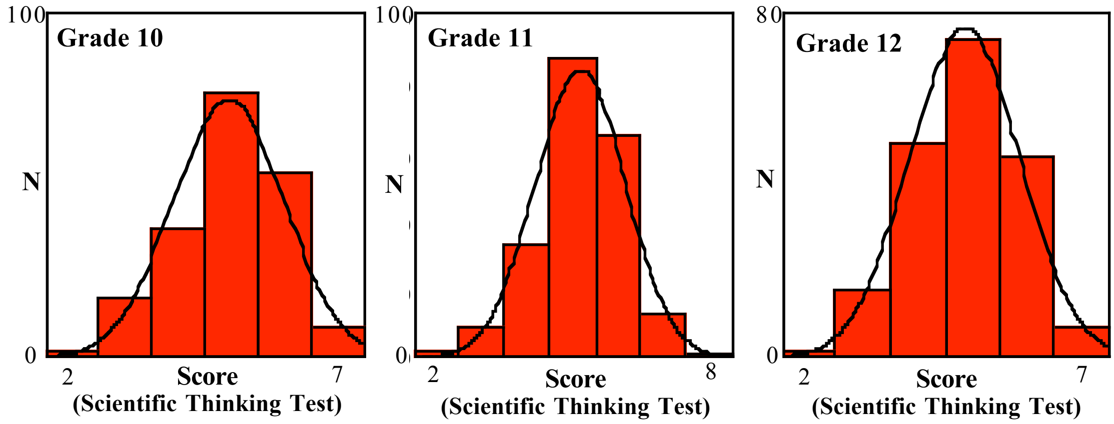


Figure 10.1 Scientific Thinking Scores

The results are shown in table 10.3 where the means and standard deviations of the performance in the test are shown for each year group for the previous session (described as 'old') and the groups who had completed the units (described as 'new').

	Sample	*Mean*	*Standard Deviation*
Grade 10	198	4.9	1.0
Grade 11	209	5.2	1.0
Grade 12	196	4.8	1.0

Table 10.3 Descriptive Statistics: Scientific Thinking Test

The means are higher than those obtained with the previous groups (who had not undertaken any teaching materials). In addition, they all seem to be very similar.

An independent samples t-test was used to see if the means differed for each year group. If the mean is significantly greater for the new groups, then the groups who completed the units have achieved a better performance in the scientific thinking test. It is clear that this has happened for grades 10 and 11 but not for grade 12 (see table 10.3 overleaf)

t-Test Values					
Group	**Sample**	**Mean**	**StDev**	**t**	**p**
Grade 10 (no units)	288	4.2	1.3	6.88	< 0.001
Grade 10 (after units)	198	4.9	1.0		
Grade 11 (no units)	257	4.6	1.1	5.83	< 0.001
Grade 11 (after units)	209	5.2	1.0		
Grade 12 (no units)	264	4.9	0.9	-1.58	n.s.
Grade 12 (after units)	196	4.8	1.0		

Table 10.4 Scientific Thinking Test Data

It is possible that, by grade 12, the students have already developed some of the skills related to scientific thinking and that no further progress can be made simply by using paper-based units. Looking at the actual test averages, there is some support for this. However, it is also possible that, by grade 12, the students have become so dependent on recall skills for examination success that further development of scientific thinking skills cannot be achieved by such a short exposure to the new teaching materials.

10.5 Correlation Data

The outcomes from the scientific thinking test were correlated with the outcomes from the national examinations, using Pearson correlation. Pearson correlation is appropriate if the variables show an approximately normal distribution and this is shown:

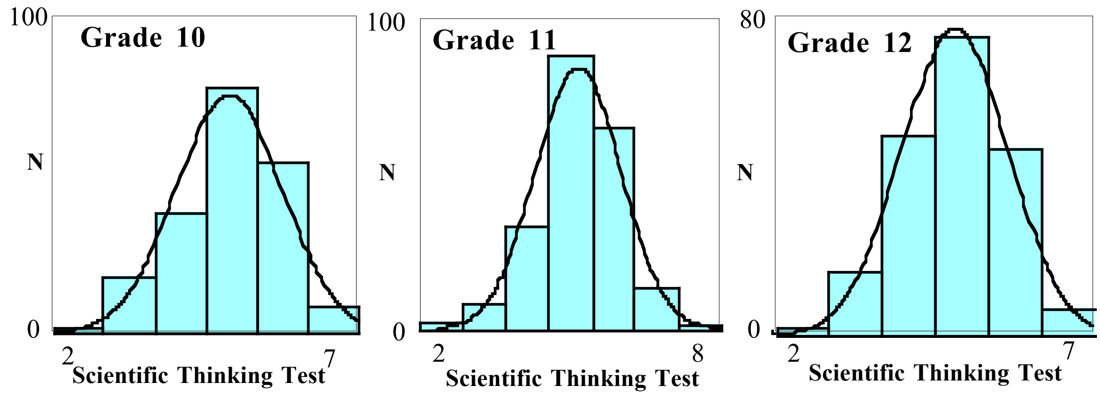


Figure 10.2 Scientific Thinking Test Distributions

Table 10.4 (overleaf) shows the pattern of correlation's obtained with the scientific thinking test.

Scientific Thinking Test Correlations			
National Examination	Year 10	Year 11	Year 12
Sample	*198*	*209*	*196*
Physics	**0.17**	0.12	0.05
Chemistry	**0.20**	0.10	0.10
Biology	**0.19**	0.13	0.09
Mathematics	**0.25**	**0.17**	-0.01
	p < 0.05	**p < 0.01**	no sig

Table 10.5 Correlation Data (Scientific Thinking)

Correlations of the national examinations with the scientific thinking test, as before, are low. It is also apparent the, in every case, the value of the correlation coefficient falls with age. An explanation might lie in the increasing emphasis on passing examinations with age, and the observation that success in these examinations depends on recall and recognition, skills very different from scientific thinking skills. Indeed, the emphasis on recall may be contradicting everything related to thinking! Perhaps, overall, repeated emphasis on memorisation and recall is hindering the development of scientific thinking.

10.6 Factor Analysis

It is possible to analyse the data obtained for the scientific thinking test and the four national examinations to look for underlying factors which might explain the correlations. This was carried out using SPSS, with varimax rotation applied. The scree plot showed that there were two factors with the three year groups, accounting for 92%, 90% and 89% of the variance, respectively. These are now shown:

Factor Loadings for Each Grade			
	The Variance	Factor 1	Factor 2
Grade 10	Scientific Thinking Test	0.11	0.99
	Physics Examination	0.95	0.06
	Chemistry Examination	0.95	0.10
	Biology Examination	0.94	0.09
	Mathematics Examination	0.94	0.16
Grade 11	Scientific Thinking Test	0.06	0.99
	Physics Examination	0.94	0.04
	Chemistry Examination	0.95	0.02
	Biology Examination	0.94	0.06
	Mathematics Examination	0.92	0.12
Grade 12	Scientific Thinking Test	0.03	0.99
	Physics Examination	0.92	0.02
	Chemistry Examination	0.94	0.08
	Biology Examination	0.92	0.08
	Mathematics Examination	0.93	-0.05

Table 10.6 Correlation Data (Scientific Thinking)

It is clear that the analysis gives the same outcomes for each of the three year groups. Whatever the scientific thinking test is measuring is not being measured by any of the national examinations. The four national examinations are testing the same skill: this has to be recall/recognition. Thus, factor 1 can be identified as recall/recognition while factor 2 can be identified, perhaps, as scientific thinking. This result is totally consistent with the factor analysis outcomes from the experiment described in chapter 8.

10.7 Comparisons

Two of the questions in the scientific thinking test were deliberately taken from the previous work of Serumola (2003). He used these as part of a longer test with students in Botswana and in Scotland. His data included two groups, from year 9 (age about 15), one Botswanian, the other Scottish. The group from Botswana had been given some teaching materials which aimed to enable the students to see the place of the experimental in scientific enquiry. This teaching material had similar aims to the material described here but it was set in the context of general science and not physics and was at a much simpler level.

The group from Scotland was drawn from schools who were undertaking the CASE programme (cognitive acceleration in science). While it could not be guaranteed that every student had undertaken the full programme, his thought was that, because of the nature of the materials in this programme, it was possible that such students would show greater scientific thinking skills. This was not obvious from his data and he deduced that the students were not yet fully cognitively ready for this kind of thinking.

It is possible to compare the results of his findings with those in the study here, looking at the groups from experiment 1 where they had experienced no teaching on scientific thinking and the groups where they had undertaken the five teaching units. Thus, there are now FOUR samples

Age Group	Sample Size	Country	Teaching related to Scientific Thinking
Years 10, 11 and 12	**809**	Emirates	No Teaching
Years 10, 11 and 12	**603**	Emirates	Units Used
Year 9 (Botswana)	**115**	Botswana	Some Teaching
Year 9 (Scotland)	**207**	Scotland	CASE * materials
* CASE = Cognitive Acceleration in Science Education			

Table 10.7 Comparisons

The two common questions are shown again here for clarity.

(5) Mohammed has been studying global warming and wonders how scientists know what is actually the truth about global warming. His friend suggested several ways to find the answers. These are listed:

A Read scientific books
B Talk to experts like university professors
C Carry out experiment to test the idea global warming
D Collect as much information as possible about global warming
E Assume global warming is true and act accordingly
F Use intelligent guesswork
G Look at information which has already been gathered through research
H Accept what majority of people believe is true about global warming

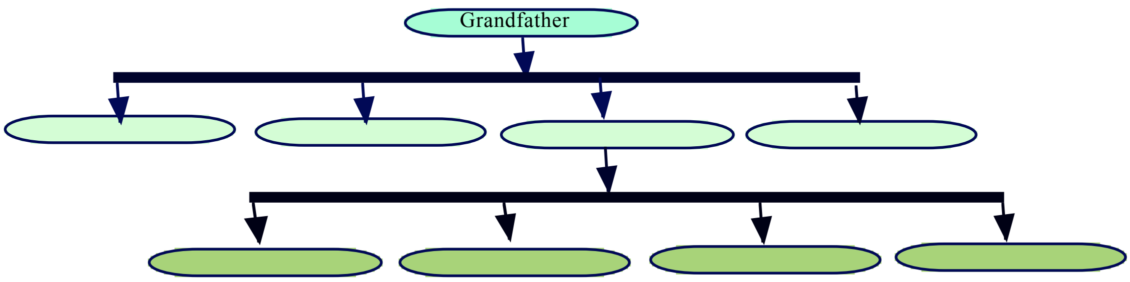
Arrange these suggested answers in order of their importance by placing the letters A,B,C...etc, in the boxes below. The letter which comes first is the most important and the letter which comes last is the least important for you.

Most important ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ Least important

(6) The table below gives information about a family, from grandfather to grandchildren. It is the year 2005.

Grandfather Still alive in the year 2005	***Aunt*** 10 years younger than uncle 2	***Uncle 1*** 4 years younger than aunt
Father In 1965, he was same age as grandfather in 1932 and 4 years younger than Uncle 1	***Uncle 2*** 2 years younger than father	***Sara*** In 1995, her age was one-fifth the age of her Aunt
Ahmad In 1990, his age was half the age of Sara	***Abdulla*** 2 years younger than Ahmad	***Maryam*** 2 years younger than Abdulla

Use the information given in the table to complete the family tree diagram below, with grandfather at the top.



What other piece of information would you need about Maryam to work out the age of her grandfather in the year 2005?

Question 5 aimed to test to see if the students had grasped the value and importance of the experimental as a source of understanding. Question 6 had two parts and the question related to a family tree. Part (a) aimed to see if the students could see the critical position of the Mother while part (b) aimed to see whether the students could spot the key connecting piece of information which was required to make interpretation easy.

The results are shown in table 10.7.

Mean Scores in Three Questions									
Q	**Year Group**	**First Group**		**Second Group**		**Botsw'a Year 9**		**Scotland Year 9**	
		N	**Score**	**N**	**Score**	**N**	**Score**	**N**	**Score**
5	Year 10	288	0.61	198	0.65	115	0.75	207	0.66
	Year 11	257	0.66	209	0.70				
	Year 12	264	0.68	196	0.69				
6a	Year 10	288	0.56	198	0.49	115	0.24	207	0.31
	Year 11	257	0.69	209	0.69				
	Year 12	264	0.75	196	0.68				
6b	Year 10	288	0.47	198	0.37	115	0.23	207	0.30
	Year 11	257	0.47	209	0.54				
	Year 12	264	0.54	196	0.42				

Table 10.8 Comparisons with Previous Studies

In table 10.8, the first group were the students in the Emirates who had not experienced any of the teaching materials while the second group had used the materials. The Botswana and Scottish groups were all younger (age about 14-15). In general, the performance in the two parts of question 6 improves with age. This suggests that the skills measured in this question develop with age or experience. In question 5, the Botswana and Scottish groups perform better. It is difficult to see exactly why this is so.

The differences in performance can be explored for the Emirates groups using a t-test. The data for the Botswana and Scottish groups is not available - only summaries are published. The t-test results are shown in table 10.9.

		First Group			Second Group		
		Year 10	**Year 11**	**Year 12**	**Year 10**	**Year 11**	**Year 12**
	N	**288**	**257**	**264**	**198**	**209**	**196**
Q 5	*Mean*	0.61	0.67	0.68	0.65	0.70	0.69
	Std Dev	0.17	0.16	0.17	0.18	0.17	0.16
	t	**2.40**	**1.60**	**0.72**			
	p	**< 0.05**	**n.s.**	**n.s.**			
Q 6a	*Mean*	0.57	0.67	0.76	0.48	0.68	0.67
	Std Dev	0.50	0.47	0.59	0.50	0.47	0.47
	t	**1.95**	**0.34**	**1.80**			
	p	**n.s.**	**n.s.**	**n.s.**			
Q 6b	*Mean*	0.45	0.49	0.54	0.36	0.53	0.40
	Std Dev	0.49	0.50	0.49	0.48	0.50	0.49
	t	**2.05**	**0.08**	**3.00**			
	p	**< 0.05**	**n.s.**	**< 0.01**			
Total Test	*Mean*	4.20	4.60	4.94	4.90	5.10	4.80
	Std Dev	1.30	1.10	0.95	1.00	0.96	1.02
	t	**6.90**	**4.80**	**1.58**			
	p	**< 0.001**	**< 0.001**	**n.s.**			

Table 10.9 t-test Data for Scientific Thinking Test Items

In table 10.8, the t-test values show the comparison between the First Group and the Second Group for each year, for question 5, 6a, 6b and the whole test. This shows that, on the specific skills measured in questions 5 and 6b, there are some improvements with group 2 (who undertook teaching materials on scientific thinking) but these are not very large.

10.8 Final Conclusions

This chapter has addressed two questions:

(a) *Do the use of teaching materials specifically designed to develop scientific thinking skills actually bring about an improvement in such skills, as measured by the test?*

(b) *Compared to younger groups (Botswana and Scotland), is there evidence that the older groups in the Emirates perform better in two questions from the test of scientific thinking skills?*

For the first question, students in grades 10 and 11 developed enhanced scientific thinking skills (as measured by the test developed) while there was no improvement for grade 12. The lack of improvement in grade 12 might simply reflect that they have reached as high as they can for their age and experience or it could simply be a caused by the fact that grade 12 students are under very high examination pressure and, as scientific thinking brings no credit in these examinations, they were not so committed in undertaking the teaching units with enthusiasm. Observation of these students as they undertook the units would seem to confirm this.

For the second question, for two of the three parts measured, the older groups showed very marked better performance. While this evidence is limited and the validity of the questions is open to challenge, it might suggest a developmental factor at work.

Chapter Eleven

More on Working Memory and Physics Understanding

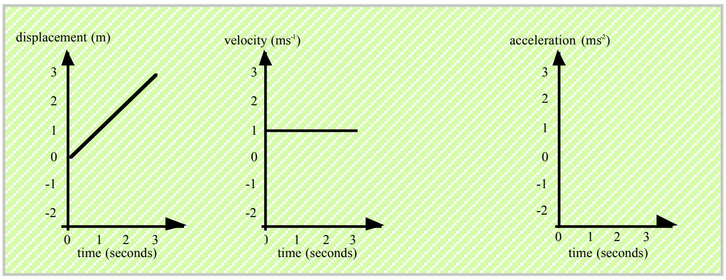
11.1 Introduction

The relationship between working memory capacity and success in a test which deliberately had been designed to measure the understanding and application of ideas in physics was described in chapter 8. The aim in all of this was to see how scientific thinking (as measured by the test developed in this study) related to other measures: physics understanding, national examination data and working memory capacity.

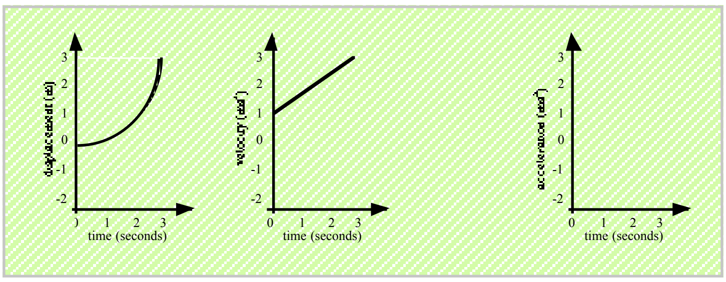
The whole areas of physics understanding was then explored in more detail, using a new test of physics understanding and application. Access was gained to the national examination data for physics, chemistry, biology and mathematics. The new test of physics understanding and application was developed in two versions: one for year 10 and the other for years 11 and 12, the two versions reflecting the different stages of syllabus coverage, some questions being common, some different. The year 10 test is now shown in full.

11.2 Year 10 Test

(1) The figure below shows the displacement-time graph and the velocity-time graph for a box moving in a factory.
Complete the third graph for the movement, showing the acceleration.



Another box moves in a different way.
Complete the third graph for the movement, showing its acceleration.



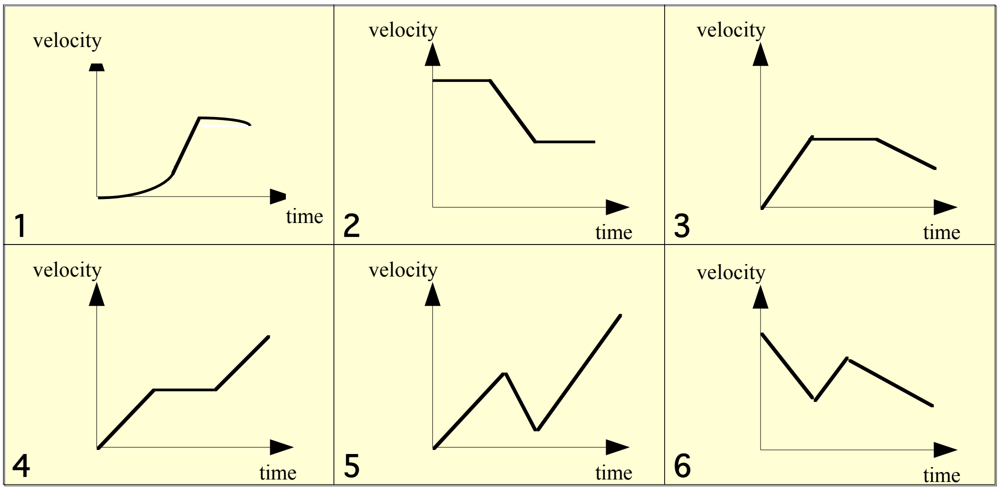
(2) When 100 ml water is cooled from 4˚C to 0˚C, it expands slightly.
Here are some statements about what is happening.
Select **ALL** the boxes which are **TRUE** *(use the numbers).*

The density and the mass of the water decrease **1**	The volume increases and the density decreases **2**	The mass, volume and density are unaltered **3**
The volume of water increases **4**	The density and the mass are unaltered **5**	The volume and density increase **6**
The density increases but the mass stays the same **7**	The mass remains constant while the density decreases **8**	The density decreases, the volume iccreases and the mass stays the same **9**

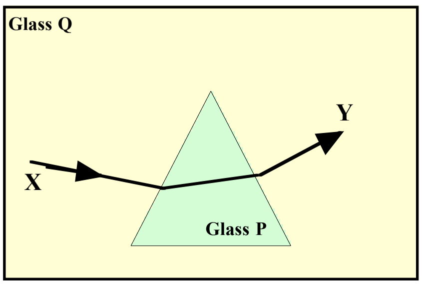
(3) The displacement of a moving ball at different times is recorded in the following table:

Time (s)	0	1	2	3	4	5	6	7	8	9	10	11
Displacement (m)	0	5	20	45	80	120	160	200	236	264	284	296

Which **ONE** of the following graphs could represent the movement (*use a number*)?



(4) In an optics exhibit at a science fair, a ray of monochromatic light travels from X to Y through a block made from two *different* types of glass, P and Q as shown below.



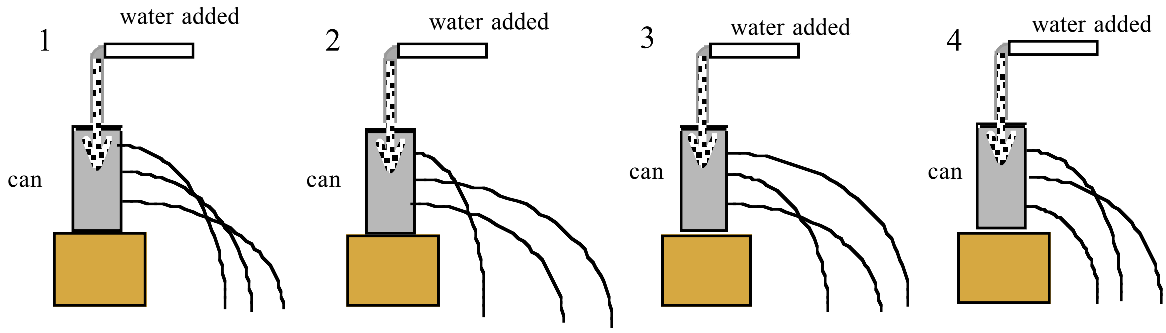
Look at each of the following statements and decide whether *each* is true (*underline to show your answer)*:

(A) Materials P and Q have different refractive indices
True ***Not true***

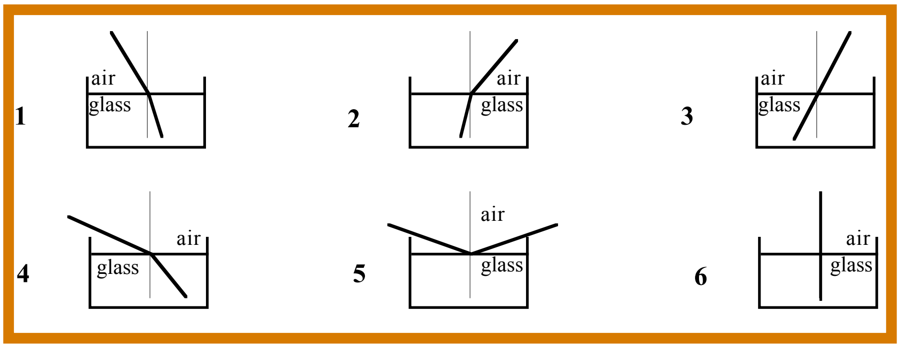
(B) Material P has a lower refractive index than material Q
True ***Not true***

(C) The light is travelling faster in material P than in material Q
True ***Not true***

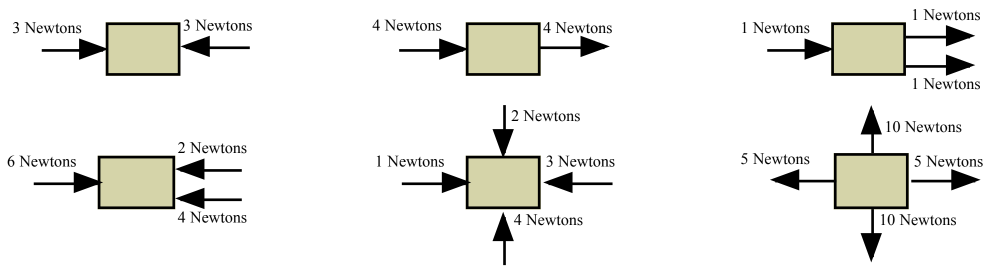
(5) A can is sitting on top of a block of wood. There are three holes down the side of the can.
The can is filled with water. As water escapes through the holes, more water is added continuously.
Which of the four pictures shows what you would expect to see?



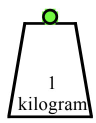
(6) A light beam travels *from* air towards a block of glass.
Which one of the following diagrams is *impossible* ? (*Put a ring round the answer*)

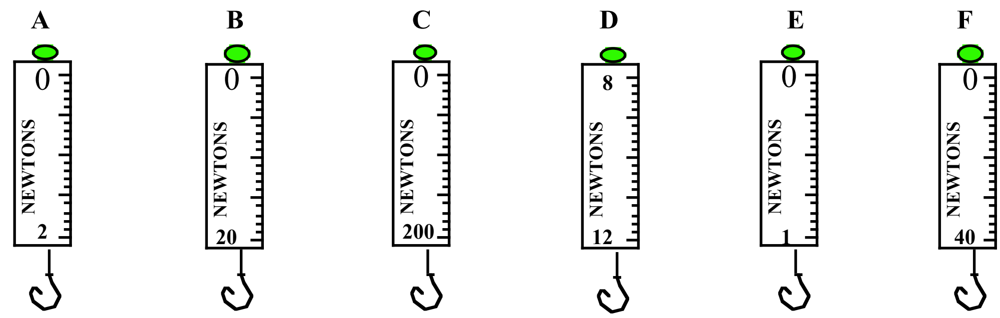


(7) Look at the six pictures below.
Put a ring round the pictures where the forces are balanced.



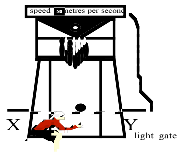
(8) A student carries out an experiment to measure the weight of a block.
The block is marked as having a mass of 1 kilogram as shown.
The student has to choose an appropriate balance. There are six balances available.
Select ***three*** balances would could be used and put them in preferred order.





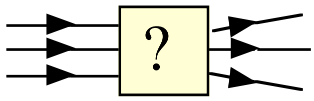
9) At a bowling alley, the speed of a ball is measured as it starts to roll along a horizontal lane.

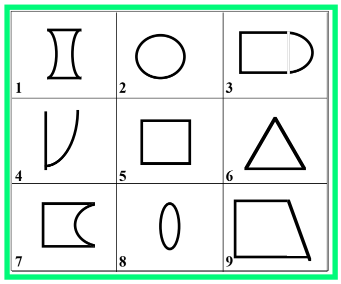
A light gate is positioned at X - Y. The light gate is connected to a computer.
The speed of the ball is measured using the light gate and the computer.



What two pieces of information does the computer need to calculate the speed of the ball?

(10) Three parallel rays of light are passed through a glass shape that is placed under a card.



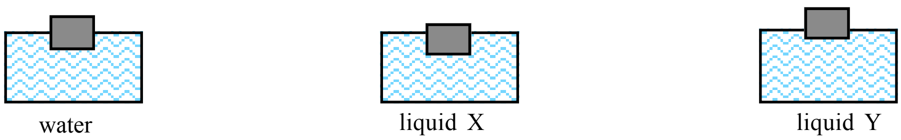


The effect of the glass shape on the rays is shown.

Which of the following could be the shape of the hidden glass shape ?

Choose *as many* as you think would work.

(11) An identical block floats on each of three liquids as shown:



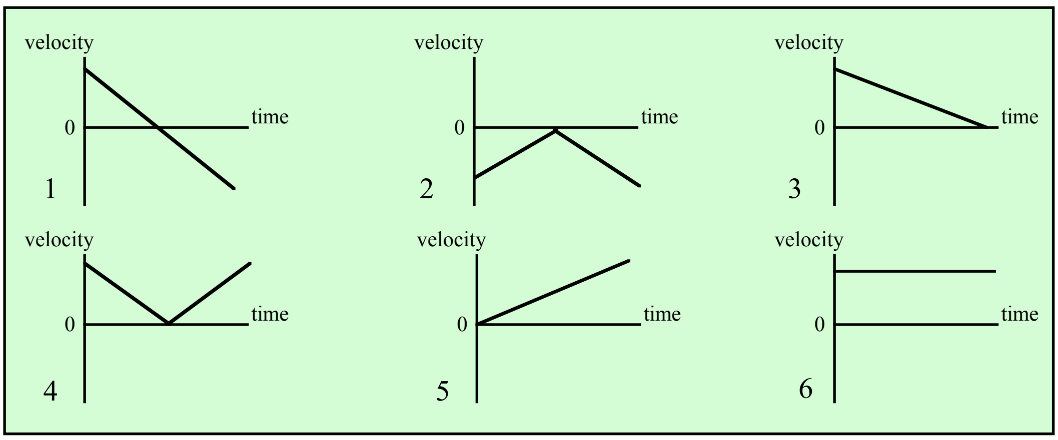
Here are three statements:

(1) The density of the material of the block is less than the density of water.
(2) The density of liquid X is less than the density of water.
(3) The density of liquid X is greater than the density of liquid Y.

Which of the statements are correct?

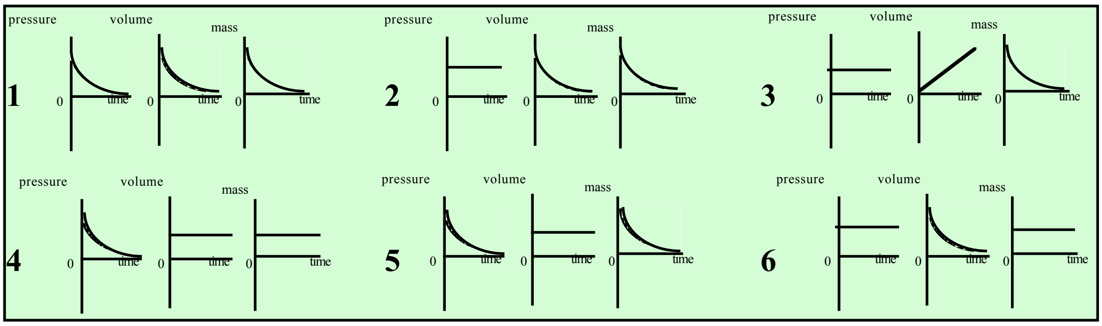
(A) Both 1 and 2 ……… (B) Both 1 and 3 ……… (C) Both 2 and 3 ………

(12) Which of the following velocity-time graphs best describes a ball being thrown vertically into the air and returning to the thrower's hand?

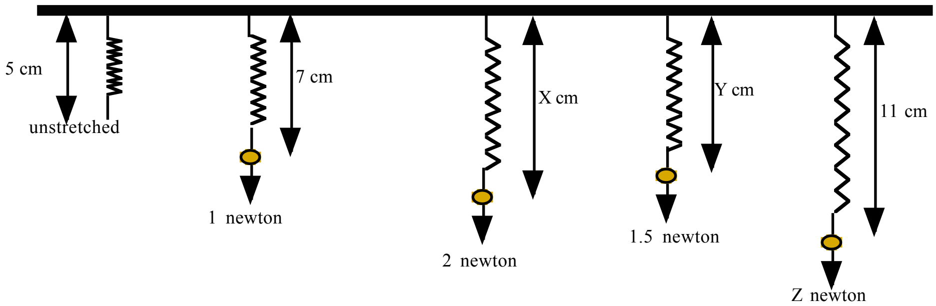


(13) A rigid metal cylinder stores some compressed air.
Air is gradually released from the cylinder.
The temperature of the air remains constant

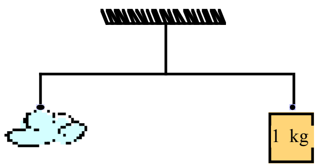
Which set of graphs shows how the pressure, the volume and the mass of the air *in the cylinder* change with time?



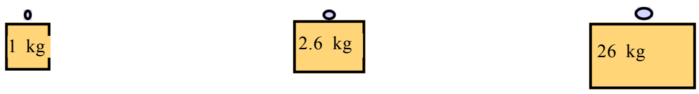
(14) The diagrams show a spring being stretched with different forces.
Find the missing values: X, Y and Z.



(15) The stone and the brass mass shown below are perfectly balanced on Earth.

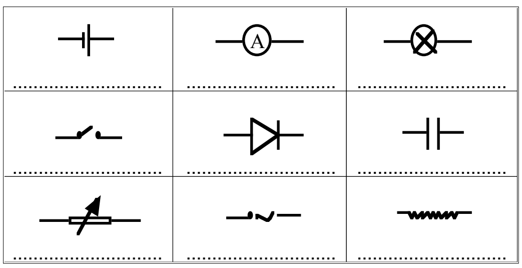


Which of these brass masses would need to be used to balance the stone on Jupiter?
Put a ring round the correct number.



1 2 3

(16) The table below shows some symbols used when you draw circuits in physics.
Write the name for each symbol on the line in in each box.



11.3 Year 11/12 Test

Only the questions which are different to those in the year 10 test are shown.

(12) The table alongside shows the result of an experiments moving a bar magnet and different coils to generate voltages.

All the voltages have been measured correctly but the student forgot to link them to right experiment.

Put the values in the correct order in the table below.

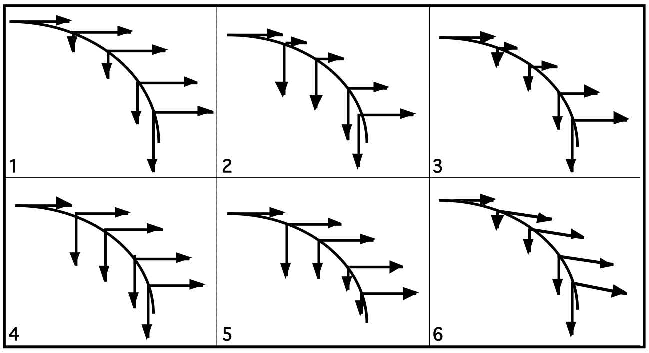
	Experiment	Induced Voltage (V)	The Correct Order
a	N S 1 m/s → ; 20 turns, stationary	0	
b	N S stationary ; 40 turns, ← 1 m/s	3.6	
c	N S 1 m/s → ; 40 turns, ← 1 m/s	1.8	
d	N S 1 m/s → ; 20 turns, 1 m/s →	5.4	
e	N S 1 m/s → ; 60 turns, ← 1 m/s	0.9	

(13) Consider a space vehicle before it re-enters our atmosphere.

It is travelling horizontally at a constant speed.

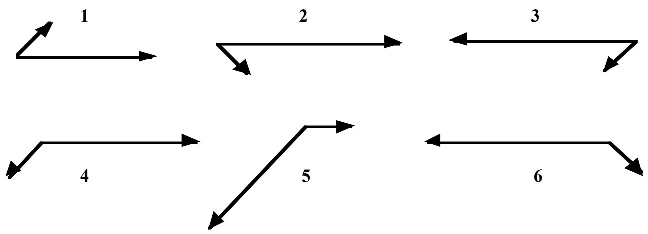
Gravity pulls on the space vehicle in a vertically downwards direction.

The vehicle follows a projectile path. Which of the figures below is right.

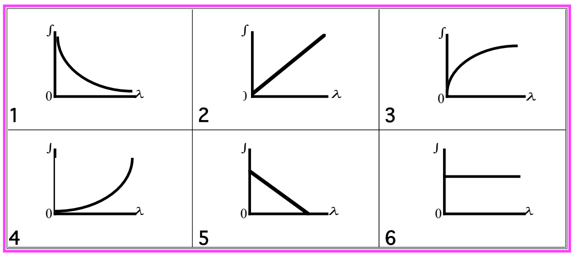


(14) The diagram below shows the resultant of two vectors:

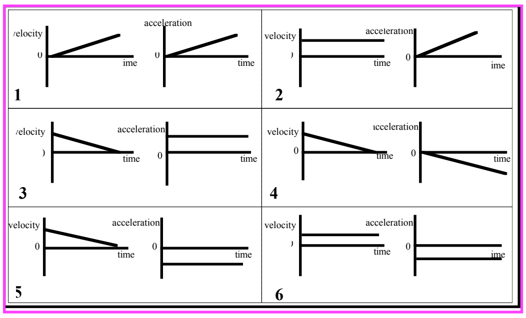
Which of the diagrams below shows the two vectors which could have produced the above resultant?



(15) Which graph shows the relationship between frequency $\int$ and wavelength λ of photons of electromagnetic radiation?



(16) The graphs in the boxes below represent the velocity and acceleration of a car moving in a straight line.

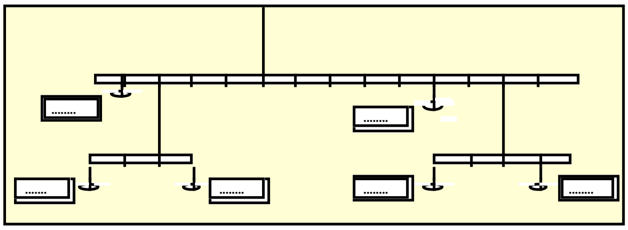


(a) Which box(es) contains a correct pair of graphs. ………………………………

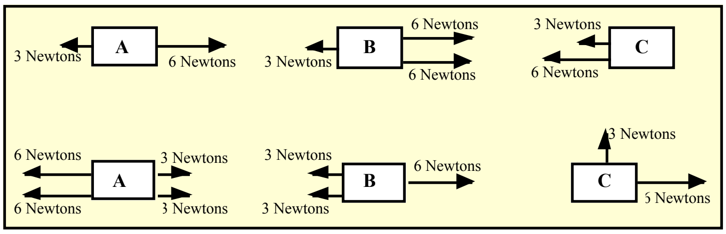
(b) Which box(es) show constant acceleration and changing velocity. ………………………………

(17) You have six separate weights of 1g,2g,3g,4g,5g and 6g.

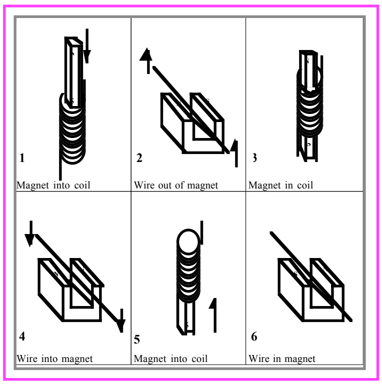
Place the six weights into the empty pans so that the scales balance.



(18) The diagrams below show the forces acting on a number of moving objects.
Which object is moving at constant speed?



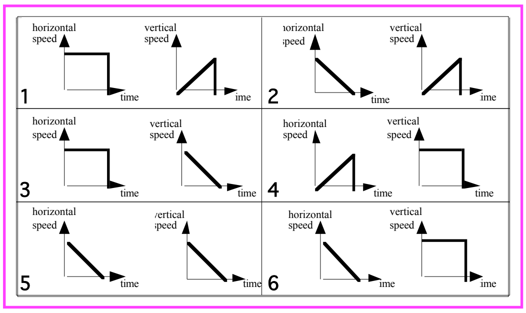
(19) Look at the following diagrams which show magnets and electrical wires.



Select all the boxes where current is generated.

.

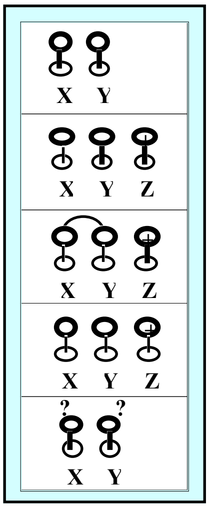
(20) A ball is kicked horizontally off the edge of cliff and lands in the sea.



Which pair of graphs shows the horizontal and vertical speeds of the ball during its flight?

The effect of air friction should be ignored.

(21) The following experiment was carried out.



Two uncharged metal balls X and Y, stand on glass rods.

A third ball, Z, carrying a positive charge is brought near the first two.

A conducting wire is then run between X and Y.

The wire is then removed.

Ball Z is finally removed.

When this is all done it is found that:
(Tick the correct answer)

☐ (A) Balls X and Y are still uncharged.
☐ (B) Balls X and Y are both charged positively.
☐ (C) Balls X and Y are both charged negatively.
☐ (D) Ball X is + and ball Y is -
☐ (E) Ball X is - and ball Y is +

11.4 Physics Understanding Tests Data

Table 11.1 shows the sample sizes which completed the test along with the means and standard deviations relating to their performance.

	Sample	*Mean*	*Standard Deviation*
Grade 10	122	9.7	3.4
Grade 11	130	10.7	3.6
Grade 12	97	12.3	3.8

Table 11.1 Descriptive Statistics: Physics Understanding Test

The distributions of scores obtained in the test of physics understanding are shown in figure 11.1. Distributions which are very close to normal are obtained for all three year groups.

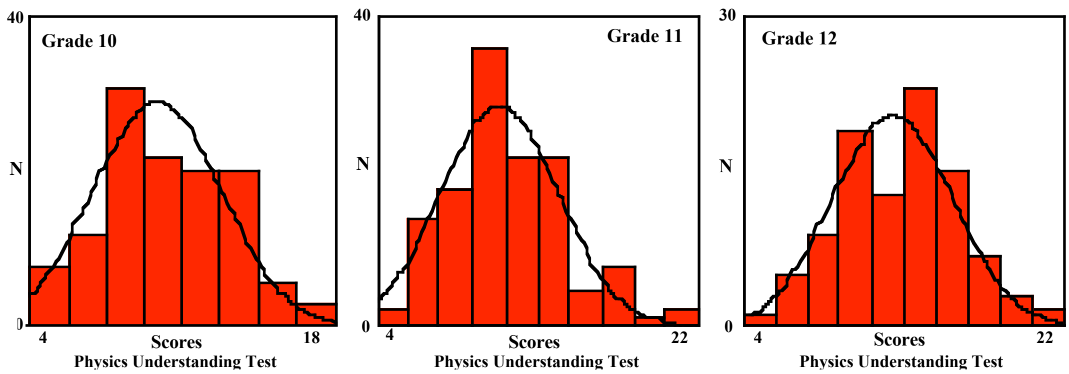


Figure 11.1 Scores Distributions: Physics Understanding Test

The physics understanding test results and the the national examination data for four subjects are correlated with the measured working memory capacity (table 11.2).

Working Memory Correlations			
Subject	**Year 10**	**Year 11**	**Year 12**
Sample	***122***	***130***	***97***
Physics test	0.05	-0.01	**0.28**
Physics	**0.47**	0.08	**0.42**
Chemistry	**0.42**	0.11	**0.26**
Biology	**0.29**	**0.18**	**0.29**
Mathematics	**0.44**	**0.14**	**0.32**
	$p < 0.05$	**$p < 0.01$**	no sig

Table 11.2 Working Memory Correlations

As expected, positive correlations are observed. However, the patterns are not easy to follow. It is important to recognise that working memory capacity will *only* correlate with performance if the tasks set make demands on working memory. The differences in the values obtained may simply reflect the specific national examinations in different years in different subjects.

Nonetheless, the physics test (designed to test understanding and application of ideas) shows a different pattern of correlation coefficients. The test was designed so that it did *not* make excessive demands on working memory and the non-significant coefficients for years 10 and 11 are consistent with this design feature. The significant result for year 12 suggests that, with these students, those with higher working memories, were at an advantage. It is not obvious why this should have been so.

The results for the four national examinations show a consistent pattern, with lower values for year 11. It is possible that this reflects styles of question used, but the consistency of the pattern does suggest something more. The possible explanation lies in a series of syllabus changes which took place in all subjects which had effects on the types of questions being asked. Indeed, in the Emirates, it seems that the curriculum in many subjects is changed very frequently.

Overall, correlations of performance with working memory capacity are known to depend on actual test questions but the values obtained here are typical values for the sciences and mathematics.

The working memory capacity was correlated with each item separately of the physics test. In grades 10 and 12, there were no significant correlations. With year 11, only three significant.

Question 4	$r = -0.18$, $p < 0.05$
Question 5	$r = 0.17$, $p < 0.05$
Question 8	$r = 0.26$, $p < 0.01$.

11.5 Factor Analysis

It is possible to analyse the data obtained for the scientific thinking test and the four national examinations to look for underlying factors which might explain the correlations. This was carried out using SPSS, with varimax rotation applied. The scree plot showed that there were three factors with the three year groups, accounting for 91%, 82% and 90% of the variance, respectively. These are now shown in the table 11.3:

Factor Loadings for Each Grade				
	The variance	**Factor 1**	**Factor 2**	**Factor 3**
Grade 10	Working Memory Capacity	0.24	0.01	0.96
	Physics Test (understanding)	0.14	0.99	0.01
	Physics Examination	0.91	0.18	0.27
	Chemistry Examination	0.94	0.08	0.20
	Biology Examination	0.90	0.06	0.03
	Mathematics Examination	0.87	0.11	0.27
Grade 11	Working Memory Capacity	0.08	-0.02	0.99
	Physics Test (understanding)	0.20	0.98	-0.02
	Physics Examination	0.90	0.08	-0.03
	Chemistry Examination	0.77	0.11	0.10
	Biology Examination	0.92	0.14	0.02
	Mathematics Examination	0.08	0.21	0.15
Grade 12	Working Memory Capacity	0.19	0.14	0.97
	Physics Test (understanding)	0.12	0.98	0.13
	Physics Examination	0.87	0.05	0.30
	Chemistry Examination	0.93	0.08	0.05
	Biology Examination	0.90	0.14	0.09
	Mathematics Examination	0.92	0.07	0.15

Table 11.3 Factor Loadings

It is clear that the analysis gives the same outcomes for each of the three year groups. The national examinations are all loading on to factor 1 and this can only be recall/recognition. The physics test was designed to assess understanding and application of physics ideas and this loads on to factor 2 which must represent understanding physics. Working memory capacity is, of course, the capacity of part of the brain and is completely different from the first two factors. The measured working memory capacity loads almost exclusively on to factor 3. This result is totally consistent with the factor analysis outcomes from the experiment described in chapter 8.

This experiment confirms what was found in the experiment described in chapter 8. It gives added confidence that the test of understanding physics was, in fact, valid. This is very different from recall and recognition. The experiment described in chapter 10 also shows that scientific thinking is not simply a form of understanding of application of ideas in physics.

Chapter 12

Insights from Eloosis

12.1 Introduction

The previous chapters have described a way to attempt to measure scientific thinking. The problem is the validity of the test which was designed. However, whatever it measures, it is *not* the same as recall-recognition nor understanding-application in relation to physics. Indeed, because the test of scientific thinking was built tightly to specifications which were drawn from the literature as well as being critically reviewed by other scientists, then there is reasonable hope that it holds some validity.

Assuming the test of scientific thinking is valid, then it is possible to increase abilities in such thinking using inserted teaching materials. It has also been shown that, in the items in the scientific thinking test which had been used previously in a study with younger students (Reid and Serumola, 2007), the older students in the Emirates, overall, had performed better.

Together, all of this suggests that scientific thinking is not easily accessible at too young an age. Perhaps about age 15-16 is the minimum age to start to seek to develop this kind of thinking. It also suggests that such thinking can be enhanced by means of teaching. Indeed, perhaps, without the right learning opportunities, the thinking might not occur much at all.

This chapter seeks to throw some light on these suggestions. It uses an academic game (called Eloosis) which is widely agreed to be useful model of scientific thinking

12.2 The Card Game (Eloosis)

Ziegler (1974) reported that Eloosis has been used successfully in science courses to teach the scientific method, especially the nature of experimentation in problem solving activities. However, it is also possible to see the game as being able to simulate the scientific way of thinking (Ziegler, 1974; Matuszek, 1995). In his study on scientific thinking, Serumola (2002) used to game with younger school students (age 12-16) to explore the extent to which they could grasp the scientific way of thinking as it relates to the nature and place of experimentation.

In his study, the game was directed with several classes (N = 120) by an experienced teacher while he recorded carefully the student reactions and responses. The teacher followed a tightly specified script which he had constructed. The student responses included answers to formal questions (which were used in a structured and consistent way) as well as the informal (and sometimes unexpected) responses from the students. He found that the game could be played easily at all ages involved in his study (ages 12-15). However, careful analysis of his data revealed that there was almost no evidence at all that the students at these ages had grasped the nature and place of experimentation as part of scientific thinking. Using this and other evidence, he argued that scientific thinking was not accessible cognitively at these ages and that to specify the teaching of scientific thinking in school syllabuses below the age of 16 was not realistic.

The plan was to follow the approach used by Serumola as closely as possible, employing the same experienced teacher and using exactly the same set of structured questions. The only difference would be that the age of the students would be older. Unfortunately, it was not possible to carry out the experiment in the Emirates because playing cards are not socially acceptable there. Instead, several groups were selected in Scotland (table 12.1).

Group	Ages	Number	Science Background
Final Year at School	17-18	Group of 15	All possessed at least one pass in a Science subject at Higher Grade
Third year undergraduates	20-21	Group of 17	Were studying for a Music education degree
Post-graduates	~22-25	2 groups of 22	All possessed a degree in a science discipline

Table 12.1 Sample chosen

In selecting the groups, the following factors were considered. The first group was drawn from students who were nearing the end of their school studies and had already passed successfully at least one science subject at the Higher Grade (university entrance level). If they were cognitively able to do so, this group was expected to be able to demonstrate that they understood fairly well the essential place of experiments as the key feature of the way the sciences gain understanding of the world .

The second group was drawn from a population of considerable intellectual ability and academic commitment but which was unlikely to contain many who had studied any of the sciences after leaving school although a few might have taken a course at the Higher Grade. This group would be likely to be cognitively well equipped to understand scientific thinking but had chosen *not* to pursue study in the sciences, their major subject being music.

The final group were those who were committed to the sciences, were cognitively mature and were expected, on grounds of their age and learning experiences, to be able to show a mature grasp of scientific thinking and, especially, the place of experimentation, the role of hypothesis testing and the use of experiments to support or falsify hypotheses.

Ziegler (1974), having used the game at high school level in the United States of America, makes the following comments:

> *"One topic that occurs in most high school chemistry courses is the scientific method of problem solving. Rather than simply lecturing to the class on the topic this experiment* (Eloosis) *allows the students to uncover the process themselves."* (p.532).

Matuszek (1995) reinforces Ziegler's comments by asserting that Eloosis requires the willingness to think from the player. Another characteristic fact about Eloosis is that it emphasises inductive reasoning or coming up with an explanation that fits the observed facts. This reflects how the game was used in the study.

The original version of the card game Eloosis was invented by Robert Abbott in 1956. The primary purpose of the game was to simulate the scientific method or demonstrate scientific investigations.

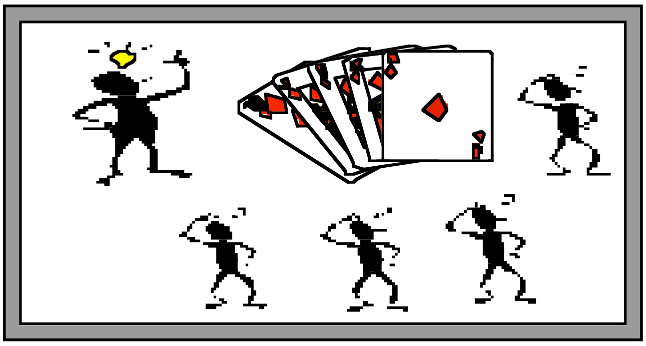


Figure 12.1 Eloosis

The technical purpose of the game is for the players to establish a pattern that could possibly be used to explain the rule of the game. Each player represents a member of a scientific research group working together on a defined problem. The group is expected to discuss their thought processes once the game is finished, as described by Ziegler (1974).

The rules for the original version of Eloosis are very simple and involve less time for play. The rules for the version of Eloosis described by Matuszek (1995) are complicated and too time consuming for the purpose of this project. Ziegler (1974) uses the rules from the original version of Eloosis. The game was played in the following way which largely adheres to the Zieglar approach.

- A group of up to around 20 was gathered around a very large table with the experienced teacher;
- One or more sets of playing cards were used;
- The cards were dealt randomly among the students each having at least 5;
- They were told to look at their cards and that they could work co-operatively, borrowing cards and discussing with each other as they wished;
- The teacher told them that he had some 'system' in his mind and that, as they played the cards (one at a time round the table), he would accept or reject each card depending on whether it fitted his system. The task of the students was to work out the system and they were allowed to intervene if they thought they had achieved this;
- The game was played several times using several systems, often of increasing complexity: with colour, suits, numbers, face and non-face cards, sequences and so on, the number of possible systems being very large;
- Any card which was accepted was left face up on the table and, after some time, there would be a series of accepted cards. The students had to study these and try to see the pattern (or system). They could then (individually or collaboratively) choose a card to play which would test their hypothesis (this word was *never* used by the teacher who also never used any scientific language during game playing or early in the questioning).
- Typical systems included: black/red alternating; suits in alphabetical order; face card/red non-face card alternating; card above 7 followed by card below 8, with colours alternating; and so on.
- The game was played three or four times with each group.

A possible way of looking at the game was collated by Serumola (2003), using the many references to the game and its use, in the literature. This is summarised in table 12.2

Activity	What is illustrated
Place the acceptable card on the table.	Collect data
Find a pattern in the accepted cards.	Search for regularities and postulate a rule, law or hypothesis
Play the next card according to the pattern	Plan and carry out an experiment to test an idea
If card is not accepted, modify or discard the hypothesis	Alter or discard a rule in favour of new experimental evidence
Tell the rest of the players what the rule is.	Share the conclusions from several experiments with the wider

Table 12.2 What Eloosis Might Illustrate

However, the key purpose in using the game (in line with what Serumola did) lay in the series of structured questions which were explored afterwards with the student group. These questions are:

Checklist For Eloosis (Scotland Sample)

Name of School ______________________ Year group ____ No. of Pupils ____

1. How many enjoyed the game?.. ☐

2. How many considered the game easy?.. ☐

3. What do you think the game taught you? ________________________________

4. Did you sometimes think you had the answer, then the next card made you changed your mind? How many?......................... ☐

5. When you thought you had it, did you try a card which you thought I would want or reverse? How many?............... ☐ rejected cards ☐ accepted cards

6. Which is better? .... ☐ rejected cards ☐ accepted cards

7. Which gives you better certainty?.................................... ☐ rejected cards ☐ accepted cards

8. How does the game relate to how science tries to find answers? ____

9. Why do you conduct experiment in science lessons? _____________________

10 What is science trying to teach us? ___________________________________

11 Are some experiments better than others? What makes a good experiment? ___

12 Are results from experiments always right? ______________________________

Figure 12.2 The Checklist of Questions (source: Serumola, 2003)

12.2 Reliability and Validity of Eloosis

Validity is considered the most important characteristic of a research instrument or test (Mason and Bramble, 1989; Wiersma, 1995). It is asserted that a valid test has to be reliable but a reliable test does not necessarily have to be valid. In the same vein, Mason and Bramble (1989) refer to the validity of the test as the degree to which the test measures what it is intended to measure. The term 'consistency' is used to imply the extent to which a test can be considered reliable (Mason and Bramble, 1989; Wiersma, 1995).

Face validity was used to measure the extent to which the test and Eloosis measured what they were designed to measure. This was achieved by using the professional opinions of a group of experienced teachers. The two methods (the test of scientific thinking and

Eloosis) used in this the study provided evidence on the consistency of pupils' conceptualisation of the place of experimentation in investigations of scientific phenomena.

12.3 Summary of Findings

The game was led by the same teacher who had led the game with Serumola (2003). The same set of instructions devised by Serumola was followed exactly. The same questions were asked in the same order, using, as far as possible, the same language. The aim was, as far as possible, to keep the experimental conditions close to those employed by Serumola with the younger students.

The tables in the following two pages (tables 12.3 and 12.4) summarise the main findings from the three groups. The first table considers mainly quantitative responses while the second table is a summary which quotes the typical actual phrases used by the students.

			Group 1 17-18 N = 15	Group 2 20-21 N = 17	Group 3 ~22-25 N = 44
1	Did you considered the game was easy?		80	53	0
2	Did you find when you had the answer, then the next card played changed your mind?		93	100	100
3	When you thought you had the answer, did you try a card which you thought I would reject?	*yes*	7	12	50
		no	93	88	9
		not sure	0	0	41
4	Did you think that "the card I want" is better?		47	70	30
5	Did you think that "the card I rejected" is better?		53	29	48
6	What was it that made you sure you had the right answer?		outcomes fitted expectation	logic hunch if fitted	observation confirmed pattern
7	Did you think that "the card I rejected" gives you better certainty?	yes	47	29	45

Table 12.3 Questions mainly with quantitative answers

		Group 1 17-18	Group 2 21-22	Group 3 23+
1	What do you think the game taught you?	related to science; involves thinking patterns; testing rules; idea about how something works; hypothesis testing	constructing ideas; thinking; testing memory; visualisation; process of elimination; mathematical logic and probability; testing errors	logical thinking, learning some pattern, team work, looking for wrong card; seeking mprovement; hypothesis testing
2	How does the game relate to how science tries to gain answers?	to find new things; to prove somethng is wrong; fitting with theory; rule following; hypothesis development; comparing things	probability; game like Sudoko; logic; find equations from the rule; science as processing to find the answers	problem solving; logical; looking for patterns; objective answers; theory not always right, what appears to be right maybe not correct answer
3	Why do we conduct experiments in science lessons?	to prove the study; to prove some is wrong; try to find new things	testing equations; process to find answers; to improve the theory is wrong by elimination; confirm an idea; to see how the world works	test theory; improve things; to find out how things work; testing things; to make advantage to benefit people
4	What is science trying to teach us	comparing things; looking for patterns; finding out how the world works; tells when an understanding is correct; getting answers	a logical process; controlling variables; getting question for which there is an answer;science as a process for finding answers	About the world around us; how things work, how we can improve quality of life, to become critical thinking
5	Are some experiments better than others?	Everyone agreed	Everyone agreed	Two thirds agreed
	If yes, what makes a good experiment?	good experiments give clear cut answers; make things practical; repeatable	one that works and can be repeated	importance; accuracy; better variable control; more valid; some better at proving or disapproving theory; related more tightly to situation
6	Are answers from experiments always right?	No one thought experiments were always right	Only one student thought experiments were always right	Everyone though experiments were always right
	Why?	only correct if done correctly	can be misleading, conducted badly	observations are observations; repetition confirms; an experiment reveals truth offers knowledge; outcomes may not be consistent with hypothesis (but still valid); attempts to explain the world around
7	How can you be certain of the answer from an experiment?	comparing with the results from others; looking at the pattern	repeat several times	Repeated many times; thngs are only right to be proved wrong; you cannot always control factor - needs care

Table 12.4 Questions mainly with longer descriptive answers

The following general conclusions can be drawn for the three groups here:

(a) Interestingly, the older the group is, the more complicated they say the game is. As they become older, they see more of the complications in the game. It gets harder as you get older.

(b) Non-scientists are least likely to go for a card which they think might be rejected and most likely to aim for an acceptable card.

(c) Those with a scientific background tend to consider that a rejected card is more informative.

(d) Those with a scientific background in their education will use generate the word 'hypothesis' and seem to have a clear idea of what is meant. They see science as related to hypothesis or theory testing.

(e) There are few marked differences between the groups in the way they see experiments but the science graduate group are the only group to see some experiments as being more informative.

(f) Part of the difference between the groups lies in the way they see experiments, with the scientist having a better grasp of the way they can be 'right' and 'wrong'.

12.4 Conclusions

One very marked observation is the very different way all three groups responded when compared to the younger groups which were studied by Serumola (2003). He noted that, while all the groups in his study had no difficulty playing the game, there was almost no evidence from the subsequent questioning and discussion that they had much idea about how the game illustrated what they were doing in their science lessons. They never used words like 'hypothesis' or 'theory' (or even expressed the ideas behind such words in their own language). They never saw the place of experimentation as a means by which idea could be tested. They seemed to see experiments largely as light relief from the teacher-led taught programme. Experiments illustrated what they had been taught. The idea of using an experiment as a means of testing, confirming or challenging ideas was almost entirely missing.

The second observation is the way the group who had more or less no scientific background reacted. They were just as competent at the game (perhaps even being the best). They enjoyed it, participated most fully and showed no sign whatsoever of being anti-science. Nonetheless, they were very much less clear than the other two groups (school science students and postgraduate science student) on the role of experimentation as a means of testing hypotheses. As might be expected, their language was different and they did not offer words like 'hypothesis' at all while even the senior school students offered this word early on in their answers and pursued the ideas of the use of experiments to confirm or undermine hypotheses quite easily, albeit with some limitations in the sophistication of language. As expected, the most mature grasp was very evident with the postgraduate group.

Overall, the evidence from the Eloosis experiment suggests that there may well be a minimum age before which understanding hypotheses and the scientific role of experimentation is inaccessible in developmental or experimental terms. Equally, the place of experience and teaching is also important.

Thus, scientific thinking may not be accessible before about the age of 16 and it will only develop if the learners are taught the sciences in such a way that the place and nature of experimentation in hypothesis confirmation and falsification is apparent (or they have gained appropriate experience in this type of thinking from other sources).

Chapter 13

Summary And Conclusions

13.1 Review of the Study

The overall aim of this project is to find out what are the features of scientific thinking which make it uniquely different from other kinds of thinking, especially critical thinking; and to explore to what extent such thinking can develop in school students in the later stages of their education. This aim produced two hypotheses:

> *(1) Genuine scientific thinking is not accessible until learners have matured developmentally and have sufficient experience of the sciences;*
> *(2) The way the sciences are taught will encourage or hinder the development of such skills.*

This aim and the two hypotheses produced four questions to which the project attempted to provide feasible answers. However, the overall conclusions will be drawn from these questions:

> (1) *What are scientific thinking skills?*
> *(2) Can they be measured?*
> *(3) Are they accessible at school level?*
> *(4) Can they be taught?*

The table below shows the possible ways which are used to find out the answers for the questions above in this project as shown in the table (13.1):

	Question	***The Way***
1	What are scientific thinking skills?	An approach to operational description
2	Can they be measured?	Develop a test where the skills give an advantage
3	Are they accessible at school level?	Cognitive development casts some doubt on this
4	Can they be taught?	Develop some new teaching materials

Table 13.1 Structure of Study

The first hypothesis involves two aspects. The first is suggested by the observations of Piaget who found that the idea of hypothesis formation did not develop until the formal operational stages (from age 12 onwards) and involves a coherent process of successive qualitative changes of cognitive structures (*schemata*) (Wadsworth, 1984). The skills will not necessarily be there at age 12 but will develop *from* age 12, Piaget emphasising that the learner can begin to test hypotheses during that stage of cognitive development. A key limiting factor is the growing capacity of working memory which has only reached a mean of 5 by age 12. It is unlikely that there is enough processing space up to that age to handle the manipulation of the ideas required for hypothesis formation (Johnstone et al., 1997). However, it then follows that such skills are not likely to be evident unless the learner has been placed in situations and experiences where such skills are taught and seen to be useful. This is the other aspect of the first hypothesis and this leads on to the second hypothesis. Here it is suggested that the way the sciences are taught may help or hinder the development of scientific thinking skills.

In order to develop some kind of operational description of scientific thinking, an extensive literature search was undertaken to see the ways in which scientific thinking was seen as different from more general critical thinking. This analysis revealed that the three areas where scientific thinking was different lay in:

* Making hypotheses
* Examining test data
* Experimenting

Thus, while scientific thinking often involved skills which others have described as aspects of critical thinking, the key unique feature of scientific thinking lay in the use of experiments as a means for developing and testing hypotheses. It is thus possible to describe scientific thinking as:

> The ability and willingness to interpret data so that hypotheses can be formulated, these being open to later testing and, perhaps, rejection or modification in the light of further experimental evidence.

13.2 The Experimental Study

The study described in this thesis involved three major experiments (table 13.2).

	The Stages of The Project	
	Aims	Measurements Made
Experiment 1	Attempt to see what is happening at age 16-18 and relate this to other aspects of performance Grade 10: N = 288 Grade 11: N = 257 Grade 12: N = 264	Develop and apply a range of tests and gather relevant data * Test of scientific thinking * Physics test based on understanding * Measure working memory capacity * Gather available examination data * Use a survey
2	Attempt to see if scientific thinking skills can be taught *Sample 1* *Sample 2* Grade 10: N = 198 N = 122 Grade 11: N = 209 N = 130 Grade 12: N = 196 N = 97	Develop new learning situations and see what happens * Development and use of teaching units * Use the same test of such thinking again * Use of a test of physics understanding * Measure working memory capacity
3	Attempt to look at other students (different ages and backgrounds) to see what is Age ~ 22+ N = 44 Age ~ 20 N = 17 Age ~ 17-18 N = 15	The use of the academic game 'Eloosis' to gain insights * With science graduates * With non-science undergraduates * With science school leavers

Table 13.2 Overview of Experiments

13.3 The Outcomes

The first experiment developed a test of scientific thinking, a test of understanding and applying ideas in physics and related both of these to national examination data and the outcomes from a test of working memory capacity. The scientific thinking test, the physics understanding test and the national examinations measured three very different things. Thus, if the test of scientific thinking is valid (it measures what was intended), then scientific thinking is unrelated to understanding or recall.

Because there is no absolute measure of scientific thinking available, the results from the scientific thinking test do not offer clear evidence that the students are thinking scientifically. Two of the questions in the test were drawn from a test used by Serumola (2000) which he used with younger learners (age 12-15). It was, therefore, possible to compare his results to those obtained here to see if there was any improvement with age. This was explored in experiment 2, along with a repeat of parts of experiment 1 to confirm the outcomes.

The first experiment also included a survey. This offers many insights into the way students ages 16-18 in the Emirates saw their learning in physics. It also showed that perceived topic difficulty was very similar to that found by Zapiti (1999) and that the differences in views of boys and girls were extremely small, consistent with the general findings from Reid and Skryabina (2003). However, the survey found little that related to scientific thinking.

The key feature of the second experiment was the careful analysis of scientific thinking and the development of five teaching units, based on relevant physics, to see if scientific thinking skills (as measured by the developed test) could be improved with targeted learning. It was clear that students in grade 10 and 11 did achieve a significantly better performance in the scientific thinking test, but it was argued that those in grade 12 had reached their upper level of such thinking already, no improvement being observed. Other analyses confirmed that the scientific thinking test certainly measured something different when compared to the test of understanding physics and all the national examinations (which tested recall-recognition). It was also clear that those in the 16-18 years age range were markedly better than the younger students (aged 12-15) in the Serumola study (Serumola, 2000) in certain aspects of scientific thinking, suggesting that his finding which suggested there were strong developmental factors was, in fact, true.

Experiment three aimed to explore this further. The hypothesis was that those with a background in one or more of the sciences would be able to interpret the meaning of the academic game Eloosis better and this was found to be the case. In addition, those with a degree in a science were able to use better language to interpret the game than those with a school science qualification but the difference lay mainly in the sophistication of language used.

13.4 Summary

The study raised four questions and generated two hypotheses. A description of the key features of scientific thinking are presented here while the outcomes from the use of both the test of scientific thinking and the academic game Eloosis are consistent, suggesting that the test was measuring something related to scientific thinking. The evidence suggest most strongly that such skills are inaccessible below the age of about 16 while they can be taught using appropriate materials. This is all summarised in table 13.3 (overleaf).

	Question	Main Findings
1	What are scientific thinking skills?	The key seems to rest with the place and nature of experimentation
2	Can they be measured?	Scientific thinking test certainly measured something different from recal and understanding
3	Are they accessible at school level?	Only at later stage (post 16 years old) in a context where they are encouraged
4	Can they be taught?	Yes

Table 13.3 Summary of Outcomes

13.5 Limitations of the Study

This study has been applied in several stages and involved vary large samples of students, representing a good cross section of the population. Thus, there can be reasonable confidence in measurements being reliable and the outcomes being generalisable. The key difficulty is being sure that the test of scientific thinking is valid. It was carefully constructed in line with the findings from the literature about the nature of such thinking and the differences between scientific thinking and the more general critical thinking. It was also considered by several experienced teachers of science subjects and amended appropriately before use.

It is also clear from the repeated factor analyses that the test of scientific thinking did not measure the same thing as recall or understanding in physics. Given the consistency of the findings using the academic game, Eloosis, there is good reasons for being optimistic that the test of scientific thinking is valid but certainty is impossible. It would have been good to conduct quite extensive interviewing but time prevented this and, in addition, interviewing boys would have been impossible for cultural reasons. Nonetheless, the discussions with the various groups who participated in Eloosis offered very useful insights which do suggest that the broad conclusions of the study are valid.

13.6 Future Work

Several future projects might emerge from this study and offer more insights:

(1) Preparation of more units, which depend on scientific thinking, to be applied in other science subjects: Chemistry, Biology and, perhaps, Mathematics for students ages 16 and over.

(2) The development of models of questions that could be used in the physics classes that might promote and foster scientific thinking with the students. These could be used with older secondary students and tested to see how they affect their thinking.

(3) Long and detailed study based on personal interviews with the students at the secondary level to check if the test of scientific thinking is valid.

(4) The use of the test of scientific thinking in a number of other countries where the educational culture in the sciences might be different. The emphasis in the Emirates is almost entirely on the rote recall of information and procedure using short questions. This might hinder the development of scientific thinking. A study in one or two western, African and Far Eastern countries would be interesting (eg Germany, Scotland, South Africa, Taiwan, Singapore).

13.7 Recommendations

A number of recommendations can be made for the development of physics (and, perhaps, chemistry and biology) education in the Emirates and elsewhere.

(a) In the Emirates, the national examination system needs major overhaul to reduce the almost total emphasis on recall.

(b) In the Emirates (and elsewhere) the need for much more overt applications in the way physics is presented. The suggested applications-led curriculum is probably a useful way forward (see Reid, 1999).

(c) In the Emirates (and elsewhere), the need to encourage teaching and learning in physics that includes the development of scientific thinking.

(d) In the Emirates, more units to be developed which could be used with students in the senior schools. These units should be designed to develop the skills which have been found from the analysis of scientific thinking. They should be designed to teach physics and, at the same time, to seek to allow students to think about the nature and place of experimentation in relation to the development of ideas in physics.

(e) In the Emirates (and elsewhere), the development of scientific thinking with younger school students (below about 16) should be removed from curriculum guidelines.

(f) In the Emirates (and elsewhere), the need to ensure that physics experimental work in schools should be illustrative of scientific thinking and consistent with the way science works.

(g) In the Emirates, textbooks should not be lists of things to be memorised but give opportunities for the students to work things out, to explore and find out patterns and so on.

(h) In the Emirates the curriculum must include mechanisms to activate thinking, scientific thinking, critical thinking.

(i) In the Emirates, there is a need to make students the focus of learning and to offer teachers the 'tools' to enable them to make the physics course more consistent with the way physics seeks answers in understanding the world around. Appropriate training will be required. Some reduction in syllabus coverage will be necessary.

13.8 Final Conclusions

In many school curricula, the development of scientific thinking is often specified. It is rarely defined and examinations almost never seek evidence that such thinking is taking place. This study has sought to explore the nature of such thinking and relate it to current understandings of learning in general. The evidence gained in this study suggests that such thinking can be taught but scientific thinking is only accessible in the later years of secondary education when cognitive development has matured sufficiently, the working memory has grown to its full size and the students have enough experience of the sciences. There are major implications for curriculum planners and for those who direct school national examinations.

Physics is an exciting subject with enormous scope for the development of understanding of the way experimentation has been used as a means to gain a more complete picture of how the physical world operates. This study seeks to offer great potentialities for the future in physics education in the Emirates and beyond, as well as raising interesting questions for future research. It is hoped that, in these ways, it may make a modest but positive contribution to physics education.

References

References

Abercrombie, M. L. (1960). Learning to think. New York: Basic Books.

Adey, P., Shayer, M., and Yates, C. (1989). Thinking Science: The curriculum materials of the CASE project. London: Thomas Nelson and Sons.

Adey, P., Shayer, M., and Yates, C. (1992). Thinking Science: The Curriculum materials of the Cognitive Acceleration through Science Education (CASE) project- Teacher Guide. London: Thomase Nelson and Son Ltd.

Adey, P. (1993). The King's-BP CASE inset pack. London: BP Educational Services.

Adey, P. (1993). History education and the promotion of intellectual development. Research proposal unsupported by the Economic and Social Research Council.

Adey, P., and Shayer, M. (1994). Really Raising Standards: Cognitive Intervention and Academic Achievement. London: Routledge.

Adey, P. (1999). The Science of Thinking, And Science for Thinking: A Description of Cognitive Acceleration Through Science Education (CASE). Switzerland: International Bureau of Education.

Adey, P. (2002). ‘We know How to Increase Intelligence,But How Do We Empower the Teachers?’, paper presented at the 10th International Conference on Thinking, Harrogate, UK, July.

Adey, P., and Shayer. M. (2002). Cognitive Acceleration Come of Age. In M. Shayer,. and P. Adey (Ed.), Learning Intelligence:Cognitive Acceleration across the curriculum from 5 to 15 years. Buckingham: Open University Press.

Adey, P., Roberston, A., and Venville, G. (2002). Effects of Cognitive Acceleration Programme on Year 1 pupils. British Journal of Educational Psychology, 72, 1- 25.

Al Tboor, A. (2007). Education History in UAE. Ministry of Education. http://www.moe.gov.ae/newmoe/uae_edu_history/uae_history.htm.

Al-Hail, H. (2005). Can you understand Physics without sketching pictures?. University of Glasgow, Glasgow. Unbublished Msc Thesis.

Al-Enezi, D. (2004). Difficulties Associated with Teaching and Learning Mathematics: A Study of Psychological Factors Affecting Performance. Unpublished MSc Thesis, University of Glasgow, Glasgow.

Al-Jumailly, A. (2006). Working Memory Overload and Molecular Simulation in Teaching Chemistry, MSc Thesis, University of Glasgow.

Al-Qasmi, S. (2006). Problem Solving in Biology at University.. Unbublished PhD Thesis, University of Glasgow, Glasgow

Allport, D. A., Antonis, B., and Reynolds, P. (1972). On the division of attention: A disproof of the single channel hypothesis. Quarterly Journal of Experimental Psychology, 24, 225-235.

Anderson, J. R. (1983). The Architecture of Cognition. Cambridge: MA, Harvard U niversity Press.

Anderson, L., Karthwohl, D., Airasian, P., Crukshank, k., Mayer, R., Pintrich, P., Raths, J., and Wittrock, M (Ed.). (2001). A Taxonomy for learning, Teaching and Assessing-A Revision of Bloom's Taxonomy of Educational Objectives: Addison Wesley Longman,I

Ashcraft, M. (1994). Human Memory and Cognition (2nd ed.). New York: Harpercollins College Publishers.

Atkinson, R. C., and Shiffrin, R. M. (1968). Human memory:Aproposed system and its control processes. In K. W. Spence (Ed.), The psychology of learning and motivation: advances in research and theroy (Vol. 2). New York: Academic Press.

Ausubel, D. P. (1958). Theory and problems of child development. New YorkGrune and Stration.

Ausubel, D. P. (1968). Educational psychology: A conitive view. New York: Holt,Rinehart and Winston.

Ausubel, D. P., and Robinson, F.G. (1969). School Learning:An Introduction To Educational Psychology. London. New York: Holt, Rinehart and Winston, Inc.

Ausubel, D. P., Novak, J. D., and Hanesian, H. (1978). Educational Psychology:A Cognitive View. (2 ed.). New York, London, Sydney: Holt,Rinehart and Winston.

Ausubel, D. P., Sllivan , E.V., and Ives, S.W. (Ed.). (1980). Theory Problems of Child Development (Thired Edition ed.). New York,London: Grune & Stratton. Ink, A Subsidiary of Harcourt Brace Jovanovich.

Averbach, E., and Coriell, A. S. (1961). Short-term memory in vision. Bell Systems Technical Journal, 40, 309-328.

Baddeley, A., Thomson, N., and Buchanan, M. (1975). Word length and the structure of short-term memory. Journal of Verbal learning and Verbal Behavior, 14, 575-589.

Baddeley, A. (1981). The concept of working memory: A view of its current state and probable future development. Cognition, 10, 17-23.

Baddeley, A. (1986). Working Memory. Oxford: Clarendon Press.

Baddeley, A. (1990). Human Memory: Theory and Practice. London: Lawrence Erlbaum Associates Ltd.

Baddeley, A. (1994). Your Memory A User's Guide. London: Penguin Group.

Baddeley, A. (1995). Memory. In C. French, and A, M. Colman. (Ed.), Cogitive Psychology. London: Longman Group Limited.

Baddeley, A. (2000). The episodic buffer: a new component of working memory? . Trends in Cognitive Science, 4, 417-423.

Baddeley, A. (Ed.). (2003). Working Memory. Oxford: Clarendon Press. Oxford.

Bahar, M., Johnstone, A. H., and Hansell, M. H. (1999). Revisting learning difficulties in biology. Journal of Biological Education, 33(2), 84-86.

Bahrick, H. P. (1984a). Semantic memory content in permastore: Fiftey years of memory for Spanish learned in school. Journal of Experimental Psychology: General, 113(1), 1-29.

Bahrick, H. P. (1984b). Memory for people. In J. E. Harris,. and P. E. Moris (Ed.), Everyday memory: Actions and absentmindedness. London: Academic Press.

Bahrick, H. P., and Hall, L. K. (1991). Lifetime maintenance of high school mathematics content. Journal of Experimental Psychology: General, 120(1), 20-33.

Bailin, S. (2002). Critical Thinking and Science Education. Science and Education, 11(4), 361-375.

Baker, H. V. (1942). Children's contribution in elementary school general discussion. Child Development Monographs, 29.

Bandura, A., and Walters, R. (1963). Social learning and personality development. New York: Holt, Rinehart and Winston.

Baron, J. (1985). Rationality and intelligence. New York: Cambridge University Press.

Baumel, H., Berger, J. (1965). An Attempt to Measure Scientific Attitudes. Science Education, 49(3), 267-269.

Behnke, F. L. (1959). Opinions of a selected group of high school science teachers and scientists on some issues related to science and science teaching. New York: Teachers College, Columbia University.

Bennett, S. N. (1973). Divergent Thinking Abilities: A Validation Study. The British Journal of Educational Psychology, 43, 1-7.

Bennett, S. N. (2004). Assessment in Chemistry and the Role of Examinations. University of Chemistry Education, 8(2), 52-57.

Beyer, B. K. (1988). Developing a thinking skills program. Boston: Allyn and Bacon, Inc.

Bliss, J. (1995). Piaget and after: The case of learning science. Studies in Science Education, 25, 139-172.

Bloom, B., and Krathwohl, D. B. (1956). Taxonomy of Educational Objevtives. New York: Handook 1: Cobnitive Domain: David Mckay.

Blunden, A. (2001). The Vygotsky School. "Spirit, Money and Modernity" Seminar. http://home.mira.net/~andy/seminars/chat.htm. Last access 3/11/2007.

Bodner, G. m. (1991). I have found you an argument: the conceptual knowledge of beginning chemistry graduate students. Journal of Cheical Education, 86(5), 384-388.

Bolton, J., and Ross, S. (1997). Developing Students Physics: Problem-Solving skills. Physics Education, 32(3), 176- 185.

Borges, A. T., and Gilbert, J. (1999). Models of Magnetism. International Journal of Science Education, 20(3), 361-378.

Boudourides, M. A. (1998). Constructivism and Education: A shopper's guide, paper at the International Conference on the Teaching of Mathemtatics, Samos, Greece, July 3-6, http://www.math.upatras.gr/~mboudour/articles/constr.html#Vygotsky%20and%20Social%2

Bourne, L. E., Dominowski, R. L., Loftus, E. F., and Healy, A. F. (1986). Cognitive Proccesses (2 ed.). London: Prentice-Hall International (UK) Limited.

Bowmen, J. G., Dall'Alba, E., Martin, D., Laurillard, F., Marton, G., Masters, P., Ramsden, A., Stephanou., and Walsh, e. (1992). Displacement, velocity, and frames of reference: Phenomenographic studies of students' understanding and some implications fo

Brainerd, C. (1978). Piaget's Theory of Intelligence. Englewood Cliffs,N.J: Prentice-Hall.

Brainerd, C. J. (1979). A neo Piagetian model of children's concept learning. Le Bulletin de Psychologie,in Press.

Brainerd, C. J. a., T.W. (1971). Training and generalization of density conservation:effects of feedback and consecutive similar stimuli. Child Dev, 42, 693-704.

Broadbent, D. E. (1975). The magic number seven after fifteen years. In A. Kennedy,. and A. wilkes (Ed.), Studies in long-term memory (pp. 3-18). London: Wiley.

Brown, D. (1989). Students' concept of force: the importance of understanding Newton's third law. Physics Education, 24(6), 353-358.

Bruner, J. (1969). The Process of Education (Vol. 11). United States of America: Harvaed University Press.Cambridge.

Bruner, J. (Ed.). (1972). The Relevance of Education. London: Redwood Press Limited.

Bruner, J. (1986). Actual Minds,Possible World. Uinted Stat of America: by the President and Fellows of Harvard College

Bruner, J. (1996). The cluture of Education. United of States of America: Harvard University Press.

Bryant, P. E. (1972). The understanding of invariance by very young children. Canadian Journal of Psychology/Revue Canadienne de Psychologie, 26(1), 78-96.

Buchdahl, G. (1993). Style of Scientific Thinking. Science and Education, 2(2), 149-167.

Byrne, M., Johnstone, A. H., and Pope, A. (1994). Reasoning science: a language problem revealed. School Science Review, 75(272), 103-107.

Byrne, M. (1983). Interactive Units for the Developent of Critical Attitudes. Simulation/Games for Learning, 13, 95-103.

Byrne. (1985). A Study of The Development Of Critical-Mindedness In Tertiary Level Students Through The Use Of Science Based Interactive Learning Unites.Unpublished PhD Thesis University Of Glasgow, Glasgow.

Cace, R., Kurland, M., and Goldberg, J. (1982). Operational efficiency and the grouth of short term memory span. Journal of Experimental Education Child Psychology, 33, 386-404.

Carey, S., Evans, R., Honda, M., Jay. E., and Unger, C. (1989). 'An experiment is when you try it and see if it works': study of grade 7 stuents' understanding of the construction of scientific knowledge. International Journal of Science Education, 11(sp), 514-529

Carey, S. (2002). The origin of concepts: Continuing the conversation. In L. Stein,. P. Bauer and M. Rabinowiz. (Ed.), Representation, memory, and development: Essays in honor of Jean Mandler (pp. 43- 52). Mahwah: NJ: Erlbaum.

Carnduff, J., Reid, N. (2003). Enhancing Undergraduate Chemistry Laboratories. The Royal Society of Chemistry, ISBN 0-85404-378-0.

Carroll, M. (2005). Experience, Intention And Practice In The Teaching Of 5-14 Primary Science.Unbublished PhD Thesis, University of Glasgow, Glasgow.

Cassels, J. R., and Johnstone, A. H. (1978). What's in a Word? New Scientist, 78(1103), 432-434.

Cellerier, G. (1972). Information processing tendencies in recent experiments in cognitive learning-theoretical implications. In s. Farnham-Diggory (Ed.), Information Processing in Children. (pp. 115-123). New York: Academic Press.

Chang, K., Liu, S., and Chen, S. (1998). Atesting system for diagnosing misconceptions in DC electric circuits. Computers and Education, 31, 195-210.

Chen, W. (2004). An Analysis of Pupil Difficulties in Physics in Relation to Working Memory Space. University of Glasgow, Glasgow.

Chenorganisers.(2007).http://www.gla.ac.uk/centres/scienceeducation/Chemorg/Topics.html

Chi, M., Feltovich, P., and Glaser, R. (1981). Categorisation and representation of physics problems by experts and novices. Cognitive Science, 5, 121-151.

Child, D. (1993). Psychology and the Teacher (5 ed.). London: Cassell.

Child, D. (2004). Psychology and the Teacher (7th Ed). London: Continuum.

Chinn, C. A., and Brewer, W. F. (2001). Models of data: A theory of how people evaluate data. Cognition and Instruction. Cognitive and Instruction, 19(3), 323-393.

Chinn, C. A., and Malhotra, B. (2002). Children's responses to anomalous scientific data: How is conceptual change impeded? Journal of Educational Psychology, 94(2), 327-343.

Christou, K. (2001). Difficulties in Solving Algebra story problems with Secondary Pupils Greek. Center for Science Education, Faclity of Education. University of Glasgow. Master(MSc), Glasgow.

Chu, Y-C. (2007). Prinate communication.

Circular 490 (1962). Physics at Ordinary and Higher Grades. Edinurgh: Scottish Examination Board.

Circular 512 (1962). Chemistry at Ordinary and Higher Grades. Edinburgh: Scottish Examination Board.

Clanchy, J., and Ballard, B. (1995). Generic skills in the context of higher education. Higher Education Research and Development, 14(2), 155-166.

Clark, R. (1971). Einstein: The Life and Times New York: World Publishing.

Clarkeburn, H., Beaumont, E., Downie, R., and Reid, N. (2000). Teaching biology students transferable skills. Journal of Biological Education, 34, 133-137.

Cone, C. A., Kendall, K. (1978). Space, time and family interactions: Visitor behavior at the Science Museum of Minnesota. Curator, 21(3), 245-258.

Costanzo, P. R., Cole, J. D., Grumet, J. F., and Farnill, D. (1973). A Reexamination of the effects of intent and consequences on children's moral judgment. Child development, 44(1), 154-161.

Craig, J., and Ayres, D. (1988). Does primary science affect girls and boys intrest in secondray science? School Science Review, 69, 417-426.

Culture, M. (2006). Eduation. Paper presented at the Proceedings of The First International Conference On The Archaeology Of The U.A.E.

Curtis. (1934). Teaching scientific methods. School Science and Mathematic, 34, 816-819.

Daneman, M., and Carpenter, P. A. (1980). Individual differences in working memory and reading. J0urnal of Verbal Learning and Verbal Behavior, 19, 450-466.

Danili, E. (2004). A study of assessment formats and cognitive styles related to school chemistry. Unbublished PhD Thesis, Glasgow University, Glasgow..

Danili, E., and Reid, N. (2004). Some Strategies to improve Performance in school chemistry, based on two cognitive factors. Research in Science and Technological Education, 22(2), 203-226.

Darwin, F. (Ed.). (1887). The Life and Letters of Charles Darwing (Vol. 1). London: printed by william Clowes and Sons,limited,Stamford Street and Charing Cross.

Department, S.O.E. (1994). Effective Learning and Teaching in Scottish Secondary Schools: The Science Edinburgh: Scottish Office Education Department.

Dewey, J. (1977). The Influence of Darwinism on Philosophy. In J. A. Boydston (Ed.), John Dewey: The middle works (Vol. 4, pp. 3-14). Carbondale: Southern Illinois University Press.

Dewey, J. (1998). How We Think. Boston: Mifflin Company.

Dicarie, T. G. (1966). Intelligence and Affectivity in Eearly Childhood:An Experimental Study of Jean Piaget's Object Concept and Object Relations(trans.Brandt.E.P.and Brandt,L.W. New York: International Universities Press.

Diederich, P. B. (1967). Components of the Scientific Attitude. Science Teacher, 34(1967).

Dierking, L., and Falk, J (Ed.). (2001). Shared Scientific Thinking in Everyday Parent - Child Activity: John Wiley and Sons, Inc.

Dierking, L., and Falk, J (Ed.). (2001). Shared Scientific Thinking in Everyday Parent - Child Activity: John Wiley and Sons, Inc.

Doise, W., and Palmonari, A. (1984). The sociopsychlological stydy of individual development. In W. D. Palmonari (Ed.), Social Interaction in Individual Development. Cambridge Cambridge University Press.

Donaldson, M. (1978). Children;s Minds. Glasgow: William Collins Sons and Co. Ltd.

Driver, R., Newton, P., and Osborme, J. (2000). Establishing the norms of scientific argumentation in classrooms. Science education, 84(3), 287-312.

Dunbar, K. (1988). Scientific Thinking and its Development: McGill University.USA.

Dunbar, K. (1995). In How Scientists really reason: Scientific reasoning in real-world laboratories. In R. J. Sternberg, and J. Davidson (Ed.), Mechanisms of insight (pp. 365-395). Cambridge: MA. MIT Press.

Dunbar, K. (1997). How scientists think: On-line creativity and conceptual change in science. In S. M. S. In T. B. Ward., and S. Vaid (Ed.), Conceptual structures and processes: Emergence, discovery and Change (pp. 1-22). Washington DC. Also reprinted in

Dunbar, K. (2000). How scientists think: on-line creativity and conceptual change in science. Science Educatin 21(1), 49-58.

Dunbar, K. (2001). What Scientific Thinking Reveals About the Nature of Cognition. In K. Crowley, Schunn, C. D., and Okada,T (Ed.), Designing for science: Implications from everyday, classroom, and professional settings. Mahwah, NJ: Lawrence Erlbaum Assoc

Duschl, R. (1990). Restructuring Science Education. New York: Teachers College.

Easley, J. (1978). Four Decades of Conservation Research.'In Knowledge and Development. In J. G. a. J.Easley (Ed.), Piaget and Education (Vol. 2). New York: Plenum.

Ebbinghaus, H. (1913). Memory A Contribution to Experimental psychology, Columbia University. Columbia: Teachers College, New York.

Edwards, J. (2005). How to Teach Thinking Skills. New Zealand: Think Shop, resources for thinking.

Egan, K. (1983). Education And Psychology;Plato,Piaget,And Scientific Psychology. New York and London: Teachers College, Columbia University.

Einstein, A. (1970). Autodiographical Notes. In P. Schilpp (Ed.), Albert Einstein: Philosopher- Scientist (Vol. 7, MJF Books). New York: The Library of Living Philosophers.

Einstein, A. and. Infield, L. (1938). The Evolution of Physics. New York: Simn and Schuster, p. 91.

El-Sawaf, M.M.F. (2007). Educational beliefs development with pre- and in-service teachers using Perry's model : a cross-cultural study, PhD Thesis, University of Glasgow.

Ennis, R. (1985). Critical thinking and the curriculum. National Forum, 65, 28-31.

Ennis, R. (1987). A taxonomy of critical thinking disposition and abilities. In J. B. Baron., and R. J. Stemberg (Ed.), Teaching thinking skills. New York: Freeman.

Ennis, R. (1989). Critical Thinking and Subject Specificty Clarification and Needed Research. Education Researcher, 18(3), 4-10.

Ennis, R. (2001). An outline of goals for a critical thinking curriculum and its assessment. Retrived Jouly 13, 2007, from http://faculty.ed.uiuc.edu/rhennis.

Ennis, R. (2002). Goals for a critical thinking curriculum and its assessment. In Arthur L. Costs (Ed). Alexandria, VA: ASCD. Pp. 44-46.

Epstein, L. C. (2002). Thinking Physics (Vol. 3). San Francisco: Insight Press 614 Vermont St.,San Francisco,CA94107.

Ericsson, K. A., and Chase, W. G. (1982). Exceptional memory. American Scientist, 70, 607-614.

Evans, J. S. (1983). Thinking and Reasoning: Psychological Approaches. London: Routledge and Kegan Paul.

Facione, P. A. (1990). Critical Thinking: A Statement of Expert Consensus for Purposes of Educational Assessment and Instruction. ERIC ED, Washington, D. C, 315-423.

Farenga, S., Joyce, B. (1999). Intentions of Young Students to Enroll in Science Courses in the Future: An Examination of Gender Differences. Science Education, 83(1), 55-75.

Fender, J., and Crowley, K (2007). How parent explanation changes what chidern learn from everyday scientific thinking. Journal of Applied Developmental Psychology, 28(3), 189-210.

Festinger, L.(1957). A Theory of Cognitive Dissonance. Stanford, CA: Stanford University press.

Festinger, L. (1964). Conflict decision, and dissonance. London: Tavistock.

Feuerstein, R., Rand, Y., Hoffman, M., and Miller, M. (1980). Insstrumentvention programme for cognitive modifiabilityal Enrichment: an inter. Baltimore: Park Press.

Feuerstein, R. (1990). The theory of structural cognitive modifiability. In Z. B, Presseisen (Ed.), Learning and thinking styles: Classroom applications (pp. 68-134). Washington, DC: National Education Association.

Feynman, R. P., Leighton, R. B., and Sands, M. (1963). The Feynman Lectures on Physics. Addison-Wesley: Reading, MA.

Fisher, A., and Scriven, M. (1997). Critical Thinking: Its Definition and Assessment. Norwich: CA, Edgepress.

Fisher, A. (2001). Critical Thinking. Cambridge: Published by the Press Syrdicate of the University of Cambridge.

Fisher, A., and Scriven. (2002). Critical Thinking. Its Definition and Assessment (Book reviews). Argumentation, 16(2), 247-251.

Fisher, R. (1995). Teaching Children to Think (3 ed., pp. 69-72). United Kingdom: Stanley Thomes (publishers) Ltd.

Fisher, S. D., Gettys, C. E., Manning, C., Mehle, T., and Baca, S. (1983). Consistency checking in hypothesis generation. Organizational Behavior and Human Performance, 31, 233-254.

Fisher, S., and Hicks, D. (1985). World Studies 8-13: A Teacher's Handbook. Edinburgh: Oliver and Boyd.

Flavell, J. H. (1963). The Developmental Psychology of Jean Piaget. NewYork, Canada, London: Van Nostrand Reinhold Company.

Flavell, J. H., and Wohlwill, J. F. (1969). Formal and functional aspects of cognitive development. In D.Elkind, J.H. Flavell (Ed.), Studies in cognitive development:Essays in honor of Jean Piaget. Toronto: Oxford University Press.

Forg, T., and Wubbels, T. (1987). Physics a problem for girls, or girls a problem for physics? International Journal of Science Education, 9(3), 297-307.

Fox, M. (1994). Psychological Perspectives in Education. New York: Cassel Educational Limited.

Fraser, D. M., and West, E. (1961). Social studies in secondary schools. New York: Ronald Press.

Frederikesn, N., William, C. (1978). Measuures for the study of creativity in scientific problem-solving. princeton,: Educational testing service.

Friedler, Y., Nachmias, R., and Linn, M. C. (1990). Learning Scientific Reasoning Skills in Microcomputer Laboratories. Journal of Research in Science Teaching, 27(2), 173-191.

Furib, C., Azcona, R., Guisasala, J and Ratcliff, M. (2000). Difficulties in teaching the concepts of 'amount of substance' and 'mole'. international Journal of Science EducatiIon, 22(12), 1285 - 1304.

Gabennesch, H. (2006). Critical Thinking: What is it good? (In Fact, What Is It?). Skeptical Inquirer, 30, 36-41.

Gagne, R. M. (1967). Science- A process approach: Purposes, accomplishments, expectations. Washington, DC: Commission on Science Education, American As- sociation for Advancement of Science.

Gallagher, J. (1987). A summary of research in science education-1985. Science Education, 71,(3), 271-273.

Gallagher, J., and Reid, D. (1981). The Learning Theory of Piaget and Inhelder. Monterey, Calif: Brooks-Cole.

Garforth, F., Johnstone, H., and Lazonby, J. (1976). Ionic equations; difficulties in understanding and use. Education in Chemistry, 13, 72-75.

Gauld, C. F., and Hukins, A. A. (1980). Scientific attitudes. Studies in Science Education: a review, 7, 129-161.

Gibbs, L. (1985). Teaching Critical Thinking at the University Level: A Review of Some Empirical Evidence. Inormal Logic, 7(2-3), 137-149.

Gilligan, C. (1982). IN a Different voice psychological Theory and Women's Development . Cambridge,: MA: Havard University Press.

Glover, J. A., Ronning, R. R and Bruning, R. H. (1990). Cognitive Psychology for Teachers. New York: Macmillan.

Gold, K. (2002). Thinking: the next big idea.TES:Website. TES:Website more than a job. Available: http://www.tes.co.uk/section/story/?story_id=365216.

Golding, C. Developing a Thinking Classroom. New Zealand: ThinkShop, resources for thinking.

Graig, J., and Ayres, D. (1988). Does primary school science affect girls' and boys interests in secondary school science? School Science Review, 69, 417 - 426.

Greenfield, T. A. (1995). An exploration of gender participation patterns in science competitions. Journal of Reserach in Science Teaching, 32, 735-748.

Greeno, J. G. (1978). Natures of problem solving abilities. In W. K. Estes (Ed.), Handbook of learning and cognitive processes (Vol. 5). Hillsdale: NJ: Erlbaum.

Greeno, J. G., and Simon, H. A. (1988). Problem solving and reasoning. In R. C. Atkinson., R. J. Hernstein, G. Lindzey., and R. D. LUCE (Ed.), Steves handbook of experimental psychology. New York: Wiley.

Grotzer, A., Zero, P. (2007). Learing the Habits of mind that Enable Mathematical and Scientific Behavior: Booklet 2 Issues of Instructional Technique in Math and Science Learning. Exxon Education Foundation to the Harvard Project on Schooling and Childre

Guenther, R. K. (1998). Human cognition. Upper Saddle River: NJ: Prentice Hall.

Guesne, E. (1985). Light. In R. Driver, E. Guesn., and A.Tiberghine (Ed.), Children;s Ideas in Science. Milton Keynes: Open University Press.

Gunsttone, R. F., and R. Wight. (1981). Understanding of gravity. Science Education, 65(3), 291-299.

Haidar, A. H. (1999). Emirates pre-service and in-service teachers' views about the nature of science. International Journal of Science Education, 21(8), 807-822.

Haidar, A. H. (2002). Emirates secondary school science teacher's perspectives on the nexus between modern science and arab culture. International Journal of Science Education, 24(6), 611-626.

Hall, C. S., and Lindsey. (1957). Theories of personality. New Yourk: Wiley.
Halpern, D. (1998). Teaching Critical Thinking for Transfer Across Domains. American psycological Association, 53(4), 449-455.

Hamilton, W. (1859). Lectures on metaphysics and logic, Vol. 1. Edinburgh: Blackwood.

Haney, R. E. (1964). The Development of Scientific Attitudes. Science Teacher, 31(33-35).

Hare, W. (1983). Open-mindedness and Education. Canada: McGill-Queen's University Press.

Harlen, W., Holroyd, C., and Byrne, M. (1995). Confidence and understanding in teaching science and technology in primary schools. Edinburgh: Scottish Council for Reserch in Education.

Hassan, A., Hill, R., and Reid, N. (2004). Ideas Underpinning Success in an Introductory Course in Organic Chemistry. University Chemistry Education, 8, 40 - 51.

Haussler, P. (1987). Measuring students' interest in physics-design and results of a cross-sectional study in the Federal Republlic of Germany. International Journal of Science Education, 9(1), 79-92.

Hayes, J. R. (1981). The Complete Problem Solver. Philadelaphia and Pennsylvania: The Franklin Institute Press.

Hearnshaw, L. S. (1987). The Shaping of Modern Psychology. London: Routledge and Kegan Paul.

Hebb, D. O. (1949). The Organization of Behaviour. New York: John Wiley.

Heller, J., and Reif, F. (1984). Prescribing effective human problem-solving processes: Problem description in physics. Cognition and Instruction, 1, 177 - 216.

Heller, J., and Reif, F. (1984). Prescribing effective human problem-solving processes: Problem description in physics. Cognition and Instruction, 1, 177 - 216.

Heller, P., and Lin, H. (1992). Teaching physics problem solving through cooperative grouping. Part 1: Group versus individual problem solving. . American Journal of physics,, 60, 637 - 644.

Herron, J. D. (1975). Piaget for chemists, explaining what good students can not understand. Journal of Chemical Education, 52(3), 146-150.

Hindal, H. (2007). Cognitive Characteristics of Students in Middle Schools in State of Kuwait, with Emphasis on High Achievement. Glasgow University Glasgow. Unbublished PhD Thesis.

Hintzman, D. (1978). The Psychology of learning and memory. San Francisco: W. H. Freeman.

Hitch, G. J., and Towse, J. N. (1995). Working memory: What develops?. in F. E. Weinert., and Schnelder.(Ed.). Memory pertomance and competencies: Issues in grouth and development. Mahwah, NJ: Erlbaum.

Hoffmann, L., Haubler, P., and Lehrke, M. (1998). Die IPN-Interessenstudie Physiik [The IPN Study of Interests in Physics]: Kiel: Ipn-Institute for Science Education at the University of Kiel.

Holbrook, N., Devonshire. (2005). Simulating Scientific thinking online: an example of research-led teaching. Higher Education Research and Development, 24(3), 201 - 213.

Hodson, D., and Hudson, J. (1998). From constructivism to social constructivism: A Vygotskian perspective on teaching and learning science', School Science Review,. 79(289), 33-41.

Hong-Kwen, B., and Kok-Aun, T. (1998). An Investigation on asacientific Thinking Ability of Fourth Year University Students. Resarch in Science Education, 28(4), 491-506.

Hoover, K. (1984). The elements of social scientific thinking. Clearwater, FL, U.S.A.

Hudgins, B. B. (1972). Learning and thinking. IIIinois: Peacock.

Huffman, D. (1997). Effect of Explicit Problem Solving Instruction on High School Students'/Problem Solving Performance and Conceptual Understanding og Physics. Journal of resrarch in science teaching, 34(6), 551 - 570.

Hung, W., and Jonassen, D. (2006). Conceptual Understanding of Causal Reasoning in Physics. International Journal of Science Education, 28(13), 1601 - 1621.

Hussein, F. (2006). Exploring Attitudes and Difficulties in School Chemistry in the Emirates. Glasgow University, Glasgow.

Hyde, D. M. G. (1970). Piaget and conceptual development: with A cross-cultural study of number and quantity. London: Holt,Rinehart and Winston.

Inhelder, B. (1953). Criteria of the stages of mental development. In J. M. Tanner., and B.Inhelder (Ed.), Discussion on child development:A consideration of the biological,psychological and cultural approches to the understanding of human development and behavi

Inhelder, B. (1962). Some aspects of Piaget's genetic approach to cognition. In W. Kessen., and C. Kuhlman (Ed.), Thought in the young chold.Monographs of the Socity for Research in Child Development (Vol. 26, pp. 19-40).

Inhelder, B., and Piaget, J. (1958). The grouth of logical thinking from childhood to adolescence. New York: Basic Books. Routledge and Kegan Paul Ltd.

Johnson, M. K., and Hasher, L. (1987). Human learning and Memory. Annual Review of Psychology, 38, 631-668.

Johnstone, A. H., Morrison, T. and Sharp, D. (1971). Topic Difficulties in Chemistry. Education in Chemistry, 8, 212.

Johnstone, A. H. (1972). An Evaluation of new Scottish Chemistry Syllabuses, PhD, Thesis. University of Glasgow, Glasgow.

Johnstone, A. H. (1974). Evaluation of Chemistry Syllabuses in Scotland. Studies in Science Education, 1, 21-50.

Johnstone, A. H., and Mughol, A. (1976). Concept of physics at secondary School level. Physics Education, 11, 466 - 469.

Johnstone, A. H., and Mughol, A. (1978). The Concept of eEectrical Resistance. Physics Education, 13, 47 - 49.

Johnstone, A. H., and Kellett, N. (1980). Learning Difficulties in School Science-Towards a working Hypothesis. European Journal of Science Education, 2(2), 175-182.

Johnstone, A. H., and Reid, N. (1981). Intractive Teaching Materials in Science. Teachers Journal, 812, 4-41.

Johnstone, A. H., Percival, F., and Reid, N. (1981). Is knowledge Enough? Studies in Higher Education, 6(1), 77-84.

Johnstone, A. H., and Reid, N. (1981). Towards a Model for Attitude Change. International Journal Science Education, 3(2), 205-212.

Johnstone, A. H., and El-Banna, H. (1986). Capacities, demands and processes - a predictive model for science education. Education in Chemstry, 23(3), 80-84.

Johnstone, A. H., MacGuire, P. R. P. (1987) Techniques for Investigating the Understanding of Concepts in Science, International Journal of Science Education, 9, 565-577.

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. (1991). Why is Science Difficult to Learn? Things are Seldom What They Seem. Journal of Computer Sssisted Learning, 7, 75-83.

Johnstone, A., and Al-Naeme, F. (1991). Room for Scientific Thought? International Journal of Science Education, 13(2), 187-192.

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. (1992). Thinking about thinking - a practical to practical work. In R. Kempa, F., Waddington, D. J (Ed.), Bringing Chemistry to Life (Vol. 69-76). London: Royal Society of Chemistry.

Johnstone, A. H., Hogg, W., 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. (1993). The development of chemistry teaching. Journal of Chemical Education, 70, 701-705.

Johnstone, A. H., Sleet, R and Vianna, J. F. (1994). An Information Processing Model of Learning: its application to an undergraduate Laboratory couse in Chemistry. Studies in Higher Education, 19(1), 77-87.

Johnstone, A. H. (1997). Chemistry Teaching - Science or Alchemy? Journal of Chemical Education, 74(3), 262-268.

Johanstone, A. H., Hogg, W., and Raja, S. (1997). How long is a chain?Reasoning in Science. School Science Review, 78(285), 73-77.

Johnstone, A. H., Watt, A., and Zaman, T. (1998). The students attitude and cognition change to a physics laboratory. Physics Education, 33(1), 22-29
.
Johnstone, A. H., Sleet, R. J and Vianna, J. F. (1999). The Use of Mini-projects In An Undergraduate Laboratory Course In C hemistry. Quimica nova, 22(1), 138-146.

Johnstone, A. H. (2001). Can problem solving be taught? University Chemical Education, 5(1), 12 - 18.

Johnstone, A. H., Selepeng, A. (2001). Language problem revisited. CERAPIE, 2(1), 19-29.

Johnstone, J., and Kean, E. (1992). Improving Science Teaching in Multicultural Settings: A Qualitative Study. Journal of Science Education and Technology, 1(4).

Jones, H. G., Mooney, R. J. (1981). An approach to conceptual difficulties in physics. Physics Education 16(6), 356-359.

Keil, F. C. (1989). Cocept, kinds, and cgnitive development. Cambridge: MA: MIT Press.

Kelly, A. (1988). Option choice for girls and boys. Research in Science Technology Education, 6(1), 5 - 23.

Kempa, R. F., and Nicholls, C. E. (1983). Problem-Solving ability and cognitive structure an exploratory investigation. European Journal of Science Education, 5(2), 171-184.

Kenneth, R. H., Donovan, T. (2007). The Elements of Social Scientific Thinkng. U.S.A: Wadsworth pub Co.

Kepler, J. (1952). The Harmonies of the world, Book V. Great Books of the Western World (Vol. 16). Chicago: Encyclopaedia Britannica. Originally published in 1619.

Kesner, M., Hofstein, A., and Ben-Zvi, R. (1997). Student and teacher perception of industrial chemistry case studies. International Journal of Science Education, 19, 725-738.

Kim, E., and Jae, S. (2002). Students do not overcome conceptual difficulties after solving 1000 traditional problems. American Journal of Physics 70(7), 759-765.

Kintsch, W., and Van Dijk, T. A. (1978). Towards a model of discourse comprehension and production. Psychological Review, 85, 363-394.

Kirschner, P., Sweller, J., and Clark, R. (2006). Why Minimal Guidance During Instruction Does Not work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. Educational Psychologist, 41(2), 75-

Klahr, D. (1994). Searching for cognition in cognitive models of science. Psycoloquy, 5(69).

Klahr, D., and Dunber, K. (1988). Dual space in scientific reasoning Cognitive Science, 12, 1-48.

Klausmeier, H. J., with the assistance of Sipple, T. S. (1980). Learning and teaching concepts-a strategy for testing applications of theory. New York: Academic Press.

Klimesch, W. (1994). Neoconnectionism and Information-Processing Stages: Do They Connect?.The Structure Of Long-Term Memory: A Connectivity Model of Semantic Processing. Book Reviews.

Klimesch, W. (1994). The Structure of Long-Term Memory A Connectivity Model of Semantic Processing. Hove, UK: Lawrence Erlbaum Associates, Publishers.

Koestler, A. (1959). The Sleepwalkers: A History of Man's Changing Vision of the Universe. England: Penguin, Arkana.

Kong, S. (2006). Effects of a Cognitive-Infusion Intervention on Critical Thinking Skills and Dispositios of Pre-service Teachers.

Kong, S. (2007). Critical Thinking Disposition of Pro-service Teachers in Singapore: A Preliminary Investigation. National Institute of Education, NTU, Singapore.

Koponen, I., Mantyla, T. (2006). Generative Role of Experiments in Physics and in Teaching Physics: A suggestion for Epistemological Reconstruction: Dpartment of physical Science, University of Helsinki, Finland.

Koslowski, B. (1996). Theory and evidence: The development of scientific reasoning. Cambridge: MIT Press.

Kozulin, A. (1997). Psychological Tools A Sociocultural Approach to Education Cambridge. Mass: Harvard University Press.

Kozulin, A. (1999). Vygotsky's Psychology: A Biography of Ideas. Cambridge: Harvad University Press.

Kristinsdottir, S. (2007). Lev Vygotsky. http://starfsfolk.khi.is/solrunb/vygotsky.htm. last access 3/12/2007.

Kruglak, H. (1949). The Delusion of the Scientific Method. American Journal of Physics, 17(7), 451.

Kuhn, D., and Ho, V. (1980). Self-directed activity and cognitive development. Journal of Applied Developmental Psychology, 1(2), 119-130.

Kuhn, D., and Phelps, E. (1982). The development of problem-solving strategies. In H. Reece (Ed.), Adances in Child Development and Bahaviour (Vol. 17). New York: Academic Press.

Kuhn, D., Amsel, E. and O'Loughlin, M. (1988). The Development of Scientific Thinking Skills. Orlando, FL: Academic Perss.

Kuhn, D. (1989). Children and adults as intuitive scientists. Psychological Review, 96(4), 674-689.

Kuhn, D. (2002). What is scientific thinking and how does it develop? In U. Goswami (Ed.), Blackwell handbook of childhood cognitive development (pp. 371-393). Oxford: Blackwell Publishing.

Kuhn, D., Franklin, S. (2006). The second decade: What develops(and how). In a. W. Damon., R. M. Lerner (Ed.), Handbook of child psychology: Vol. 2. Cgnition, perception and language (6 ed., pp. 953-993). Hoboken, NJ: John Wiley and Sons.

Lagnado, D. (2006). Psychology: How Do Scientists Think? Science AAAS, 313(5792), 1390-1391.

Larkin, J. H., and Reif, F. (1979). Understanding and teaching problem solving in physics. European Journal of Science Education, 1, 191 - 203.

Larkin, J. H. (1983). The role of problem representation in physics In D. a. S. Gentner, A (Ed.), Mental Models. Hillsdale: NJ: Lawrence Erlbaum Associates.

Larkin, J. H., and Simon, H.A. (1987). Why a diagram is (sometimes) worth ten thousend words. Cognitive Science, 11, 65 - 99.

Lawson, A. E., and Snitgen, D. (1982). Teaching formal reasoning in a college biology course for preservice teachers Journal of Research In Science Teaching, 13(5), 413-430.

Leo, E. L., and Galloway, D. (1996). Conceptual links between cognitive acceleration through science education and motivational style: A critique of Adey and Shayer. International Journal of Science Education, 18(1), 35-49.

Liegeois, L., Chasseigne, G and Papin, S. (2003). Improving high school students' understanding of potential difference in simple electric circuits. International Journal of Science Education, 25(9), 1129 - 1145.

Lindsay, P., and Norman, D. (1977). Human Information Processing: An Introduction to Psychology (Second Edition ed.). London: Asubsidiary of Harcourt Brace Jovanovich, Publishers.

Lochhead, J., and Clement, J. (1979). Cognitive Process Instruction: research on teaching thinking skills. Philadelphia: Franklin Institute Press.

Lovell, K., Kellett, V., and Moorhouse, E. (1962). The grouth of the concept of speed: a comparative study. Journal Child Psychol. Psychiat, 3, 101-110.

Lovell, K. (1976). Understanding scientific concepts. In W. V. P. Varma, P. (Ed.), Piaget,Psychology and Education. Edinburgh: Hodder and Stoughton Educational.

Lubart, T. I. (1994). Creativity. In R. J. Sternberg (Ed.), Thinking and problem solving (pp. 289-332). London: Academic Press.

Lunzer, E. A. (1976). An appreciation of Piaget's work. In V. P. Vama, Williams, P (Ed.), Piaget, Psychology and Education (pp. 3-14). London: Hodder and Stoughton Ltd.

MacKay, D., Miller, M. (1996). Neoconnetionsm and Information-Processing Stage: Do They Connect? The Structure of Long-Term Memory: A Connectivity Model of Semantic Processing. The American Journal of Psychology, 109(1), 162-171.

Malacinski, G. (1994). Impediments to Developing Collaborative Learning Strategies: The Input vs. Output Conflict. journal of Science Education and Technology, 3(2), 107 - 114.

Malim, T. (1994). Cognitive Processes:Attention,Perception,Memory,Thinking and Language. London: The Macmillan press Ltd.

Maloney, D. (1985). Charged poles? Physics Education, 20(6), 310 - 316.

Maloney, D., O'Kuma, T., Hieggelke, C., and Van Heuelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. American Journal of Physics, 69(S1), S12-S23.

Marten, R. (1997). Scientific thinking. Canada: Broadview Press.

Mason, E. J., and Bramble, W. J. (1989). Understanding and Conducting Research: A pplications in Education and the Behavioural Sciences. Singapore: McGraw-Hill, Inc.

Mbajiorgu, N., and Reid, N. (2006). Factors Influencing Curriculum Development in Higher Education Physics. Hull: The Higher Education Academy.

Mbano, N. (2003). The effects of a Cognitive Acceleration Intervention Programme on the performance of secondary school pupils in Malawi. International Journal of Science Education, 25(1), 71-87.

McCloskey, M., Caramazza, A., and Green, B. (1980). Curvilincar Motion in the Absence of External Forces: Naive Beliefs about the Motion of Objects. Science, New Series, 210(4474), 1139-1141.

McCloskey, M., and Kohl, D. (1983). Naive physics: The curvilinear impetus principle and its role in interactions with moving objects. Journal of Experimental Psychology: Learning, Memory, and Cognition, 9, 146-156.

McDermott, L. R., M and Van Zee. (1987). Student difficulties in connecting graphs and physics: Examples from kinematics. American Journal of Physics , 55(6), 503-513.

McDermott, L. (1998). Students Conceptions and Problem Solving Mechanics In A. L. Tiberghien, E and Barojas, J (Ed.), Connecting Research in Physics Education with Teacher Education, Section C1. U.S.A: The International Commission on Physics Education.

McKendree, J., Small, C., Stenning, K., and Conlon, T (2007). The Role of Representation in Teaching and Learning Critical Thinking. Education Review, 54(1), 57-67.

McKinnon, J. W., and Renner, J. W. (1971). Are colleges concerned with intellectual development? . American Journal of Physics, 39(9), 1047-1052.

McLellan. (2006). The Impact of Motivational "World-view" on Engagement in a Cognitive Acceleration Programme. International Journal of Science Education, 28(7), 781-819.

McNally, D. W. (1970). The incidence of Piaget's stages of thinking as assessed by tests of verbal reasoning in several Sydney schools. Forum of Education, 29, 124-134.

McPeck, J. (1981). Critical Thinking and Education. Oxford: Martin Robertson.

McPeck, J. (1990). Teaching Critical Thinking dialogue dialetic. New York: Routledge.

Matuszek, D. (1995) About new Eloosis,
http://www.netaxs.com/people/nerp/eleusis0.html (last accessed 2003)

Meece, J. L., and Jones, M. G. (1996). Gender differences in motivation and strategy use in science: are girls rote learners? Journal of Research in Science Teaching, 33(4), 393-406.

Ministry OF Education And Yoth (U.A.E). (2007). Educational StrategY.
http://www.uae.gov.ae/Government/education.htm.

Millar, R., and Beh, K. L. (1993). Students' understanding of voltage in simple parallel electric circuits. International Journal of Science Education, 15, 351-361.

Millar, R., and King, T. (1993). Students' understanding of voltage in simple series electric circuits. International Journal of Science Education, 15, 339-349.

Miller, G. A. (1953). What is information measurement? American Psychologist, 8(1), 3-11.

Miller, G. A. (1956). The magical number seven plus or minus two:Some limits on our capacitu for processing information. Psycholgical Review, 63, 81-97.

Moore, T. (2004). The critical thinking debate: how general are general thinking skills? Higher Education Research and Development, 23(1), 3-18.

Mullis, I., Martin, M., Beaton, A., Gonzalez, E,. Kelly, D., and Smith, T. (1998). Mathematics and Science Achievment in the Final Year of Secondary School: IEA'S Third International Mathematics and Science Study (TIMSS): Centre for the study of Testing,

Nakhleh, M. B. (1993). Are our students conceptual thinkers or algorithmic problem solvers: Identifying conceptual students in general chemistry. Journal of Chemical Education, 70, 52 - 55.

National Guidlines 5-14. (1999). Environmental Studies Dundee: Learning and Teaching Scotland.

National Science Foundation (2004), Science and Education Indicators. Arlington, Virginia.

Neisser, U. (1967). Cognitive Psychology. New York: Appleton Century-Crofts.

Nersessian, N. J. (1992). How do scientists think? Capturing the dynamics of conceptual change in science. . In R. N. Giere (Ed.), Cognitive Models of Science. Minneapolis: University of Minnesota Press.

Newmann, F. M. (1985). Higher order thinking in the teaching of social studies: Connections between theory and practic. In J. Voss, D. Perkins., and J. Segal (Ed.), Informal reasoning and education. Hillsdale, NJ: Erlbaum.

Nickerson, R. (1985). The teaching of thinking. London: L. Erlbaum Associates.

Nickerson, R. (1986). Reasoning. In R. Dillon., and R. J. Sternberg. (Ed.), Psychology and curriculum design. New York: Acadmic Press.

Nicolson, R. (1981). The relationship between memory span and processing speed. In M. Friedman, J.and N. O'Connor (Ed.), Intelligence and learning (pp. 179-184): Plenum Press.

Nisbet, J. (1993). The thinking curriculum. Educational Psychology, 13(3 and 4), 90-28.

Norris, S. P. (1985). Synthesis of research on Critical Thinking. Educational Leadership, 42(8), 40-45.

Novak, J. D. (1958). An experimental comparison of a conventional and a project centered method of teaching a college general botany course. Journal of Experimental Education, 26(4), 217-230.

Oakes, J. (1990). Opportunities, achievement and choice: women and minority students in science and mathematics. Review of Research in Education, 60, 153-222.

Oraif, F. (2007). An Exploration of Confidence Related to Formal Learning in Saudi Arabia. Ph.D. Glasgow University, Glasgow. Unbublished PhD Thesis.

Otis, K. H. (2001). Metacognition: A Valuable Aid to Understanding for Medical Students in Problem-Based-Learning. Glasgow University, Glasgow.

Park, J. (2006). Modelling Analysis of Students' Preocesses of Generating Scientific: Explanatory Hypotheses. International Journal of Science Education, 28(5), 468-489.

Patrick, J., Costello. (2003). Thinking Skills and Early Childhood Education London: David Fulton Publishers Ltd.

Paul, R. (1992). Teaching critical reasoning in the strong sense: getting behind worldviews. In R. Talaska (Ed.), Critical Reasoning in Contemporary Culture (pp. 135-156). State University of NY: Albany.

Paul, R., and Elder, L. (2003). A Miniature Guide for Students and Faculty To Scientific Thinking. Oxford: The Foundation for Critical Thinking.

Paulo, S., and Adriano, S. (2005). Rotation in secondary school: teaching the effects of frictional force. Physics education, 40(3), 257-265.

Perkins, D. N. (1993). Creating a culture of thinking. Educational Leadership, 5(3), 98 - 99.

Peters, P. C. (1982). Even honers students have conceptual difficulties with physics. American Associatio of physics Teachers, 50(6), 501 - 508.

Physics at Standard Grade (2006). Dalkeith: Scottish Qualifications Authority.

Piaget, J. (1928). Judgment and reasoning in the child. New York: Harcourt.

Piaget, J. (1929). The child's conception of the world. London: Routledge.

Piaget, J. (1932). The moral Judgment of the Child London. Panl: Kegan,Panl.

Piaget, J. (1950). The Psychology of intelligence. New York: Harcourt.

Piaget, J. (1952). The origins of intelligence in children. New York: International Universities.Press.

Piaget, J. (1953-54). Les relations entrel affectivite et l intelligence dans le developpement mental de I' enfant Ball de Psychol (Vol. 7).

Piaget, J. (1954). Language and thought from the genetic point of view. Acta Psychologica, 10, 51-60.

Piaget, J. (1954). The costruction of reality in the child. New York: Basic Book.

Piaget, J. (1957). Logique et equilibre dans les comportements du sujet. In L. Apostel., B. Mandelbort., and J.Piaget. (Ed.), Logitudes depistemologie genetique.que et equiliber.E (Vol. 2, pp. 27-117). France: Paris:Presses Univer.

Piaget, J., and Inhelder, B. (1959). La genes des structures logiques, elementaires:classifications at seriations. Neuchatel: Delachaux et Niestle.

Piaget, J. (1961). Les Mecanismes Perceptifs. Paris: PUF.

Piaget, J. (1962). Play, Dreams and Imitation in Childhood. New York: Norton.

Piaget, J. (1964). Development and learning. In R. E. Ripple., and V. N. Rockeastle (Ed.), Piaget

rediscovered.A report of the Conference on Cognitive Studies and Curriculum Development. Press: Ithaca:Cornell University.

Piaget, J. (1965). Psychology and philosophy. In B. Wolman., and E. Nagel (Ed.), Scientific Psychology. New York: Basic Books.

Piaget, J. (1969). The mechanisms of perception. New York: Basic Books.

Piaget, J., and Inhelder, B. (1969). The Psychology of the Child.Translated by Helen Weaver. New York: Basic Books

Piaget, J. (1973). The affective unconscious and the cognitive unconscious. J. Am.Psychoanalyt. Assoc, 21(2), 249-264.

Piaget, J. (1974). The chiled and reality: Problem of genetic psychology. London: Muller.

Piaget, J. (1977). Psychologist of the Real Brian Rotman. Bristol: Bristol Typesetting Co.Ltd.,Barton Manor - St.Philips.UK.

Prosser, M., Walker, P and Millar, R. (1996). Differences in Students' Perceptions of Learning Physics Physics Education, 31, 43-48.

Psillos, D., and Koumaras, P. (1993). Multiple causal modeling of electrical circuits for enhancing knowledge intelligibility. In M. Caillot (Ed.), Learning Electricity and Electronics with Advanced Educational Techniques. New York: Springer Verlag.

Quinn, M. E., and George, K. D. (1975). Teaching hypothesis formation. Science Education, 59(3), 289-296.

Raja, S. H. (1992). Development Of Scientific Reasoning In Primary And Early Secondary School Pupils. University of Glasgow, Glasgow.

Ramsden, J. M. (1998). Mission impossible?: Can anything be done about attitudes to science. International Journal of Sciece Education, 20(2), 125 - 137.

Ramsey, G. A., and Howe, R. W. (1969). An analysis of research related to instructional procrdures in elementary science. Science and Children, 6, 25-36.

Reich, R. B. (1991). The work of Nations: Preparing Ourselves for 21st Century Capitalism. New York: A. A. Knoopf. .

Reid, N. (1978). Attitude Development Through A Sciense Curriculum. University of Glasgow.PhD thesis, Glasgow. Unbublished PhD Thesis.

Reid, N. (1991). Choice and Change in the Curriculum, Times Educational Supplement Scotland.

Reid, N. (1999). Towards an Application-led Curriculum. Staff and Educational Development International, 3(1), 71 84.

Reid, N. (2000). The presentation of Chemistry Logically Driven or Applications-Led? Chemistry Education: Research and Practice in Euroup, 1(3), 381-392.

Reid, N., and Skyrabina, E. (2002a). Gender and Physics. International Journal of Science Education, 25(4), 509-536.

Reid, N., and Skyrabina, E. (2002b). Gender and Physics, *International Journal Science Education,* **25**(4), 509-536.

Reid, N., and Yang, M. (2002a). Open-ended problem solving in school chemistry: a preliminary investigation. International Journal of Science Education, 24(12), 1313-1332.

Reid, N., and Yang, M. J. (2002b). The Solving Problem in Chemistry: The More Open Ended Problem Reaearch in Science and Technological Education, 20(1), 83-98.

Reid, N. (2003a). Gender and Physics. International Journal of Science Education, 25(4), 509-536.

Reid, N. (2003b). Getting Started in Pedagogical Research in Higher Education, LTSN Physical Science. Higher Education Academy, Hull, ISBN 1-903815-07-X.

Reid, N., and Serumola, L. (2006). Scientific Enquiry: The Nature and Place of Experimentaion: a review. Journal of Scirnce Education, 7(1), 1-15.

Reid, N., and Serumola, L. (2007). Scientific Enquiry: The Nature and Place of Experimentation: some recent evidence. Journal of Science Education, 7(2), 88-94.

Reid, N. (2008). A Scientific Approach to the Teaching of Chemistry The Royal Society of Chemistry, Nyholm Lecture, Chemistry Education Reasearch and Practice, 9(1), in press.

Reif, F., Larkin, J. H. and Barackett, G. C. (1976). Teaching general learning and proble solving skills. American Journal of Physics, 44, 212 - 217.

Reigosa, C., Pilar, M., Alexixandre, J. (2001). Deciding how to observe and frame events in an open physics problem. Physics Education, 36(2), 129 - 134.

Rennie, L. J., and Parker, L. H. (1993). Curriculum reform and choice of science: consequences for balanced and equitable participation and achievement. Journal of Research in Science Teaching, 30(9), 1017 - 1028.

Resnick, L. B. (1985). Instruction and the cultivation of thinking. In E. D. Corte., J. G. Lodewijks,., R. Paramentier., and Span (Ed.), Learning and instruction. Oxford: Pergamon Press.

Resnick, L. B. (1987). Education and learnig to think. Washinggton, DC: National Academy Press.

Richard, P. (1985). Bloom's Taxonomy and Critical Thinking Instruction. Educational Leadership, 42(8), 36-39.

Rieber, R., and Robinson, D (Ed.). (2004). The Essential Vygotsky. New York, Boston: Kluwer Academic/Plenum Publishers.

Raja, S. H. (1992). Development of Scientific Reasoning In Primary And Early Secondaray School Pupils. University of Glasgow, Glasgow.

Rogoff, B. (1990). Apprenticeship in thinking. Cognitive development in social context. New York: Oxford University Press.

Scottissh 5-14 Guidelines. (2000). http://www.ltscotland.org.uk/5to14/images/guidelinesenvironmental_tcm4-122445.pdf. (last accessed 27th November 2007).

Schafersman, S. (1994). An Introduction to Science: Scientific Thinking and the Scientific Method. http:/www.freeinquiry.com/intro.html.

Schibeci, R. A. (1984). Attiyudes to science: An update. Studies in Science Education, 11, 26-59.

Schimer, S. (1968). Acompariso of student outcoes in various earth science courses taught by 17 lowa teachers. A National Association for Research in Science Teaching Paper.

Scholastic's magazine.(1996). Seven Steps to thinking Like a Scientist. for parents of young.children. . http://www.scholastic.com/earlylearner/parentandchild/science/7steps.pdf.

Schrag, F. (1987). Thoughtfulness: Is high school the place for thinking? Newsletter, National Center on Effective Secondary Schools, 2, 2-4.

Scottish Qualifications Autheority. (1997). Scottish Certificate of Education Standard Grade Arrangement in Biology, Chemistry and Physics (three volumes), General and Credit Levels in and after 1999. Edinburgh: Scotish Qualifications Authority.

Serumola, L. B. (2003). A Study of Scientific Thinking with Young Adolescents. University of Glasgow, Glasgow

Seymour, E., and Hewitt, N. (1997). Talking About Leaving: Why Undergraduates Leave the Sciences. Boulder: Co: Westview, Press.

Shah, I. (2004). Making University Laboratory Work in Chemistry More Effective. Glasgow University, Glasgow. Unbublished PhD Thesis.

Shanxi, W. (2002). A Scientific creativity test for secondary school students. International Journal of Science Education, 24(4), 389-403.

Sharpe, P. (1938). Why Not Use Control Experiments? Science Education, 22(1), 19-22.

Shayer, M. (1999). Cognitive acceleration through science II: its effects and scope. International Journal of Science Education, 21(8), 883-902.

Shayer, M., and Adey, P. S. (1981). Towards a Science of Science Teaching. London Heinemann Educational Books.

Shayer, M., and Wylan, H. (1978). The distribution of Piagetian stages of thinking in British middle and secondary children 11-14 to 16 year olds and sex differentials. British Journal of Educational Psychology, 48, 62-70.

Shayer, M., Kuchemann, D. E., and Wylan, H. (1976). The distributio of Piagetian stages of thinking in British middle and secondary school children. British Journal of Educational Psychology, 46, 167-173.

Shayer, M., Kuchemann, D. E., and Adey, P. S. (1978). Science reasoning tasks. UK, National Foundation for Educational Research, Slough.

Siegel, H. (1980). Critical Thinking as an Educational Ideal. Educational Forum, 45(1), 7-23.

Siegel, H. (1984). Critical Thinking, Philosophy, and the Informal Logic Movement. Paper presented at the Second International Conference on Critical Thinking and Educational Reform, Sonoma State University, Sonoma, California.

Simone, H. A. (1974). How Big is a Chunk? Science. Science Education, 183(8 February), 482-488.

Simon, H. A. (1989). The scientist as problem solver. In K. D, and K. Kotovsky (Ed.), Complex information processing: The impact of Herbert A. Simon. Hillsdle, NJ: Lawrence Erlbaum.

Sirhan, G., and Reid, N. (2001). Preparing the Mind of the learner - part 2, . University Chemistry Education, 5, 52-58.

Sirhan, G., Gray, C., Johnstone, A. H., and Reid, N. (1999). Preparing the Mind of the Learner. University Chemistry Education, 3(2), 43-46.

Skryabina, E. (2000). Students Attitude to Learning Physics at School and University Levels in Scotland. University of Glasgow, Glasgow. Unbublished PhD Thesis.

Slak, S. (1970). Phonemic Recoding of Digital Information. Journal of Experimental Psychology, 86(3), 398-406.

Smith, B. O. (1960). Critical thinking. In Recent research developments and their implications for teacher education. 13th Yearbook, American Association of Colleges for Teacher Education. Washington, D.C: The Association.

Soy, E. M. (1967). Attitudes of prospective elementary teachers towards science as a field of specialty, School. School , Science and Mathematics, 67, 507-517.

Sperling, G. (1960). The information available in brief visual presentations. Psychological Monographs, 74(498), 1-29.

Stadlert, H. D., R and Benke, G. (2000). Do boys and girls understand physics differently? Physics Education, 35(5), 417 - 422.

Stephen, T., Sue Dale, T. (2001). Looking for ideas: observation, interpretation and hypothesis-making by 12-year-old pupils undertaking science investigations. International Journal of Science Education, 23(8), 791-813.

Sternberg, R. (1996). Cognitive Psychology London: Harcourt Bract College Publishers.

Stokking, K. (2000). Predicting the choice of physics in secondary education. International Journal of Science Education, 22(12), 1261 - 1283.

strategy.(2006).
http://www.bin-ad.net/vb/showthread.php?t=5575. http://www.uae.gov.ae/images/educat2.jpg

Stronk, D. R. (1974). The sociological backgrounds of scientifically talented secondary school students throughout the state of Texas. Journal of Research In Science Teaching, 11, 31-37.

Stuessy, C. (1984). Correlates of scientific reasoning in adolescents: Experience, locus of control, age, filed dependence-independence, rigidity/flexibilty, IQ, and gender. Unpublished doctoral dissertation. Columbus, Ohio, USA.

Styer, D. (2001). The whys and hows of physics problems: Oberin College Physics.

Sullivan, E., V. (1967). Experiments in the acquisition of conservation of substance:An overview. In D. W. B. a. E.V.Sullivan (Ed.), Recent research on the acquisition of conservation of substance: Education Monograph,Ontario Institute for studies in Edu

Sutherland, P. (1992). Cognitive Development Today: Piaget and his Critics. Liverpool: Paul Chapman Publishing Ltd.

Sutherland, P. A. (1982). An expansion of Peel;s describer-explainer stage theory. Educational Review, 34(1), 69-76.

Swarts, R., and Parks, S. (1994). Infusing the teaching of critical and creative thinking into content instruction:nA lesson design handbook for the elementary grades. California: Critical Thinking Press and Software.

Swartz, R. J. (1987). Critical thinking, the curriculum, and the problem of transfer and teaching. In J. L. D. Perkins, and J. Bishop (Ed.), Thinking: Progress in research and teaching. Hillsdale, NJ: Erlbaum.

The National Consultative Council. Report of the Committee on Education and Information on the assessment. (2006).). Ab Dhabi: The classification of the performance of government and private education in Abu Dhabi Emirate

The National Media Council. News & Information on the United Arab Emirates (UAE). (2007). http://uaeinteract.com/education/.

Thornton, R. (1987). Tools for scientific thinking-microcomputer-based laboratories for physics teaching Physics Education, 22, 230 238.

Tobias, S. (1993). What Makes Science Hard? A Karplus Lecture. Journal of Science Education and Technology, 2(1), 297-304.

Totten, S. (1991). Introduction. In T. In: S.Totten., Sills., A, Digby., and P, Russ (Ed.), Cooperative Learning: A Guide to Research (pp. 1-18). New York: Garland Publishing.

Towase, J., Hich, G and Hutton, U. (1998). A Reevaluation of Working Memory Capacity in Children. Journal of Memory and Language, 39(2), 195-217.

Tulving, E. (1972). Episodic and semantic memoey. In E. T. a. W. Donaldson (Ed.), Organisation of Memory. London: Academic Press.

Tweney, T., Doherty, M., and Mynatt, C. (1981). Scientific Thinking. New York: Columbia University Press.

Uzgaris, I. C. (1964). Situatioal generality of conservation. Child Development, 35(3), 831-841.

Venger, A., and Gorbov, S. . (1993). Psychological foundations for an introductory course of mathematics for six year olds. Focus on Learning problems in Mathematics, 15, 2-13.

Vernon, P. E. (1976). Environment and intelligence. In V. P. Varma, Williams,P. (Ed.), Piaget,Psychology and Education. Edinburgh: Hodder and Stoughton Educational.

Vygotsky, L. S. (1962). Thought and Language. Cambridge, MA: The Massachusetts Institute of TechnologyPress.

Vygotsky, L. S. (1974). Thought and Language. USA: The Massachusetts Institute of Technology.

Vygotsky, L. S. (1986). Thought and Language (translated and edited by A. Kozulin). Cambridge: MIT Press, Mass.

Vygotsky, L. S. (Ed.). (1978). Mind in Society: The Development of Higher Psychological Processes. London: Harvard University Press.

Vygotsky, L. S. (1978). Mind in society: the development of higher psychological processes. Cambridge: Harvard University Press.

Vygotsky, L. (1997). Thought and Language. Newly revised by Kozulin, A. Cambridge: The MIT Press England.

Wadsworth, B. J. (1971). Piaget's theory of cognitive development. New York: D. McKay.

Wadsworth, B. J. (1984). Piagets Theory of Cognitive and Affective Development (Vol. 3). United States of America: Longman Inc.

Wallace, J. G. (1976). The course of cognitive grouth. In W. V. P. Varma, P. (Ed.), Piaget,Psyvhology and Education. (pp. 15-30). London: Hodder and Stoughton Ltd.

Watts, M., and Pope, M. (1989). Thinking about thinking, learning about learning: constructivism in physics education. Physics Education, 24, 326-327.

Weinburgh, M. (1995). Gender Differences in Student Attitudes toward Science: A Meta-Analysis of the Literature from 1970 to 1991. Journal of Research In Science Teaching, 32(4), 387- 398.

Wenham, M. (1993). The nature and role of hypotheses in school investigations. International Journal of Science Education, 15, 231-240.

Wheatley, G. H. (1984). MEPS Technical Report, Mathematics and Science Centre, Purdue University.(cited from Zoller, U.(1987). The fostering of question-asking capability. Journal of Chemical Education, 64(6), 510-512.

Wiersma, W. (1995). Research Methods in Education: An Introduction. Needham Heights: Allyn and Bacon.

Wikipdia. (2007). http://en.wikipedia.org/wiki/Theory.

Wilkening, F., and Sodian, B. (2005). Scientific reasoning in young children: Introduction. Swiss Journal of Psychology, 64(3), 137-139.

Williams, R. (2003). Higher Order Thinking Skills: Shallenging All Students to Achieve. California: Corwin Press.

Witkin, H., A., Dyk, R. B., Paterson, H. F., Goodehough, D. R., and Karp, S. A. (1974). Psychological Differentiation - Studies of Development. New York: Wiley.

Wohlwill, J. F. (1973). The study of behavioral development. New York: Academic Press.

Womack, D. (1988). Developing Mathematical and Scientific Thinking in Young Chidren. London: Cassell education limited.

Wood, C., and Sleet, R. J. (1993). Creative Problem Solving in Chemistry. London: The Royal Society for Chemistry, London.

Woolnough, B. (1994). Why students choose physics, or reject it. Physics Education, 29(6), 368-374.

Wosilit, K. H., P. Shaffer, P. and McDermott, L. (1999). Addressing student difficulties in applying a wave model to the interference and diffraction of light. American Association journal of physics Teachers, 67(7), S5 - S15.

Wright, D. S., and Williams, C.D. (1986). A wise strategy for introductory physics. The physic Teacher, 24, 211 - 216.

Yang, M. J. (2000). Problem Solving In Chemistry At Secondary School. Unbublished PhD Thesis, University of Glasgow, Glasgow.

Young, M., and Schofield, R. (1976). The Social responsibility of the physicist. Physics Education, 11(7), 498-503.

Zapiti, S. (2001). Difficulties in Learning Physics at Secondary School. University of Glasgow, Master of Science and Science Education (M.Sc), Glasgow.

Zapiti, S. (2001). Difficulties in School Physics. Glasgow: Glasgow University.

Zeidler, D., Lederman, N., and Taylor, S. (1992). Fallacies and Student Discourse: Conceptualizing the Role of Critical Thinking in Science Education. Science Education, 76(4), 437-450.

Ziegler, G. R. (1974). Eloosis-a card game which demonstrates the scientific method. Journal of a Chemical Education, 51(8), 532.

Zimmerman, C. (2007). The development of scientific thinking skills in elementray and middle school. developmental Review, 27(2), 172-223.

Zohar, A., Dori, Y., and Center for Educational Computing Initiatives Massachusetts Institute of Technology. (2003). Higher order thinking skills and Low-Achieving Students:Are they Mutually Exclusive? Journal of the learning science, 12(2), 145 - 181.

Zoller, U. (1993). Lecture and Learning: Are they compatible? Maybe for LCOS, unlikely for HOCS. Journal of a Chemical Education, 7, 195-197.

Zoller, U. (1997). Higher and Lower-Order Cognitive Skills:The Case of Chemistry. Research in Science Education, 27(1), 117-130.

Zoller, U. (2000). Teaching tomorrow's college science courses: Are we getting it right? Journal of College Science Teaching 29(6), 409-415.

Zoller, U. (2000). The Disposition of Eleventh-Grade Science Students;Toward Critical Thinking. Journal of Science Education and Technology, 9(2), 149-159.

Appendix

A
B
C
D
F
G

Appendix

A

UNIVERSITY of GLASGOW

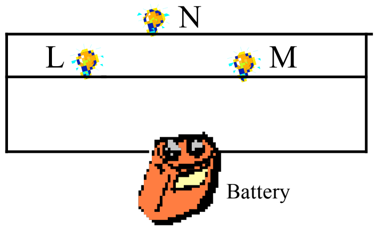
Centre for Science Education

Your Name ……………………………………………………………………

Name of school ……………………………………………………………………

Grade ……………… Class ………………

(1) In the circuit below there are 3 identical lamps: L, M and N.



When M is removed from its socket, the brightness of N does not change. Here are six statements related to what has happened

Look at the statements below. All are true.

Select all the statements which ***offer an explanation*** why the brightness of N does not change

Tick as many as you wish.

Tick here	Tick here	Statement
A		The current flowing through N does not change
B		resistance
C		L and N have the same resistance
D		L and M are in series and both are parallel to N
E		There is now no current flowing through L when M is removed
F		The voltage across N has not altered

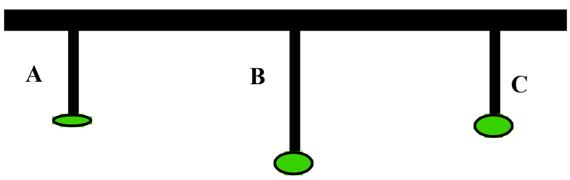
(2) You have three pendulums.

A and C have the same length of string.

B and C have an equal weight attached while A has a smaller weight.

Suppose you wanted to do an experiment to find out if changing the length of a pendulum changed the amount of time it takes to swing back and forth.

Which pendulums would you use for the experiment.

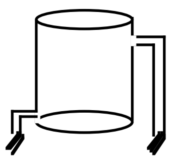


A&B ☐ B&C ☐ A&C ☐ A,B&C ☐

(3) Consider a water container. If it is filled with water ***to the top***, water can escape from the pipe at the bottom or the pipe nearer the top. Both pipes have the same diameter.

Think of the flow rate of water from each pipe when the container is full of water.

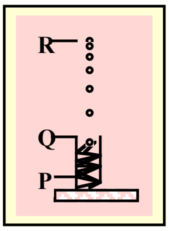
Which of the following is true?



- ☐ There is a higher flow rate from the short pipe;
- ☐ There is a slower flow rate from the short pipe;
- ☐ There is a same flow rate from both pipes.

Explain your choice of answer: ………………………………………………………………………………

(4) The figure below shows a multiflash photograph of a small ball being shot straight up by a spring. The spring, with the ball on top was initially compressed to the point marked P and released.



The ball left the spring at the point marked Q and reached its highest point at the point marked R.

Assume that the air resistance was negligible.

Here are five statements about this experiment. Tick ***all*** the statements which are ***true***.

	Tick here	Statement
A		The velocity of the ball was decreasing on its way from point Q to point R
B		The acceleration of the ball was greatest at point Q
C		The acceleration of the ball was the different at P and Q
D		The velocity of the ball was increasing on its way from point Q to point R
E		The acceleration of the ball was greatest just before it reached point R

The velocity of the ball was greatest just as it reached point Q (still in contact wuth the spring). In two sentences, explain why this has to be true:

....

....

....

....

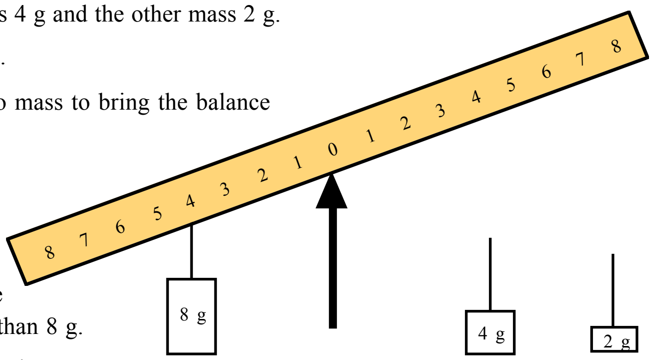
....

(5) Khalid and Reem have two mass. One mass 4 g and the other mass 2 g.

Here is a balance with an 8 g mass attached.

They wonder if it is possible to use the two mass to bring the balance level again.

Which of the following is true?
*Tick **all** the statements which are true.*



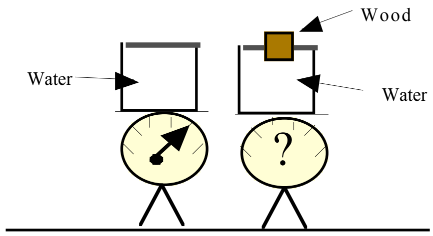
- ☐ Equilibrium cannot be achieved because the sum of the 4 g and 2 g mass is less than 8 g.
- ☐ Equilibrium can be achieved by placing the 4g mass at hole number 2 on the right and the 2g mass at hole number 1 on the right.
- ☐ Equilibrium can be achieved by placing the 4 g mass at hole number 4 on the right and the 2 g mass at hole number 8 on the right.
- ☐ Equilibrium can be achieved by placing the 4 g mass at hole number 8 on the right and the 2 g mass at hole number 0.
- ☐ Equilibrium can be achieved by placing the 4 g mass at hole number 5 on the right and the 2 g mass at hole number 8.
- ☐ Equilibrium can be achieved by placing the 4 g mass at hole number 7 on the right and the 2 g mass at hole number 2.

(6) A pair of identical containers are filled to the brim with water.

One has a piece of wood floating in it.

What is the total weight on the right hand balance ?

- ☐ The balance on the right shows the higher reading.
- ☐ The balance on the right shows the smaller reading.
- ☐ Both balances read the same

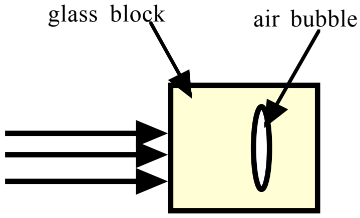


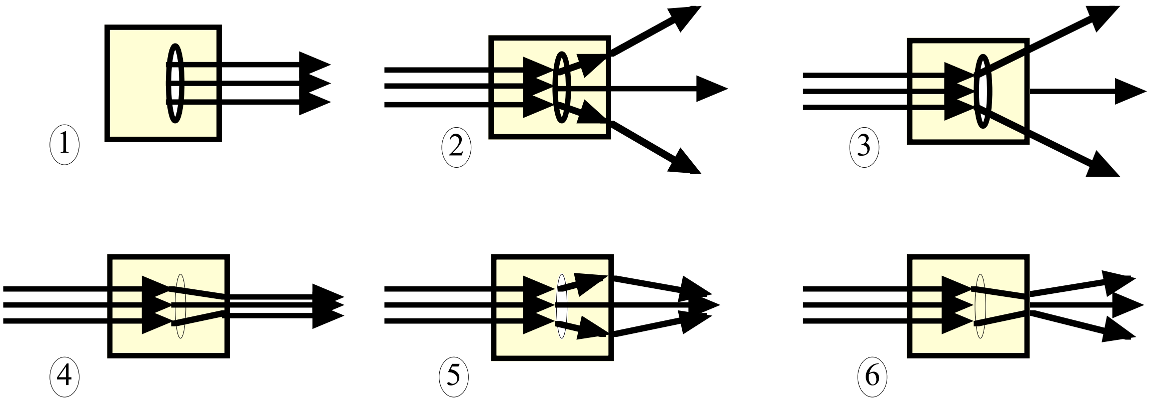
(7) Here are a picture showing three parallel rays of light which are incident on a glass block containing an air bubble.

Which picture shows the path of the rays through the block correctly?

Tick one box:

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

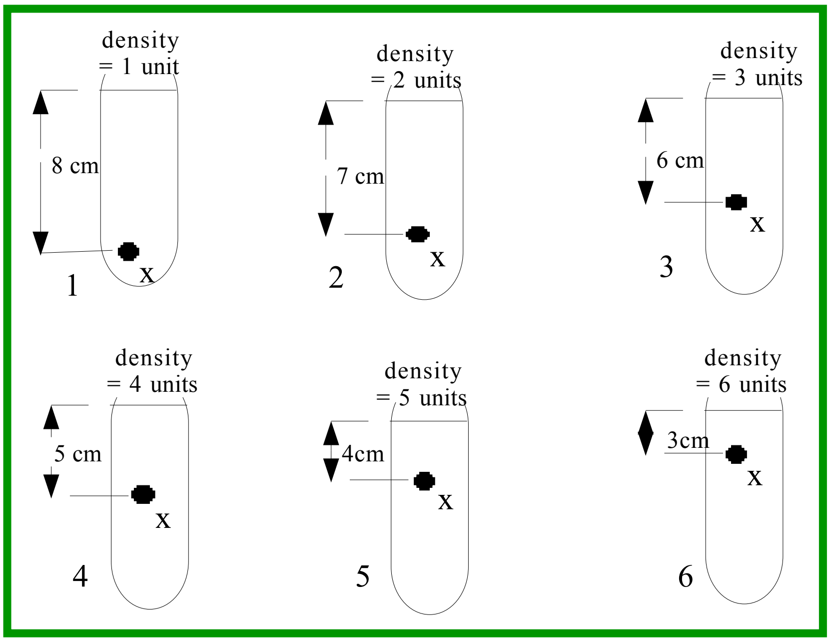




(8) The pictures below show six liquids of different density contained in a separate identical test tube. The density of each liquid is given in the diagram.

Looking at all six tubes, in which tubes are the pressures greatest at point X?
(Tick as many as are correct answers)

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐



Appendix

B

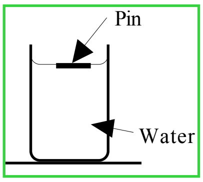
UNIVERSITY of GLASGOW

Centre for Science Education

This questionnaire is a part of a project investigating how you think when you learn physics.
All information obtained will be treated in complete confidence.
Please complete this questionnaire about your studies in physics as honestly as possible.

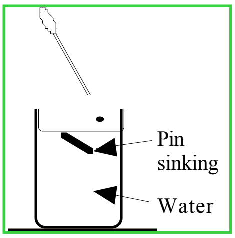
Your Name ....
Name of school:..
Grade: .... Class: ....

(1) If we carefully lay a metal pin across a water surface, it will actually float on water. Which of the following statements are ***possible explanations***.
(Tick as many as you wish)



- ☐ Particles(molecules) of the liquid form stronger bonds with each other than with particles of glass.
- ☐ The links between particles in the metal are not strong.
- ☐ The pin is less dense than the water.
- ☐ Water molecules interact with each other more strongly than they interact with the surface of the pin.
- ☐ The water molecules attract each other so strongly that the weight of the pin is not enough to break their bonds.
- ☐ Pins like this float on water

If we now put a drop of soap solution onto the water, the pin will sink.
Which of the following statements are ***possible explanations***.
(Ticks as many as you wish)



- ☐ The pin is more dense than the water.
- ☐ Particles of the liquid form stronger bonds with each other than with particles of glass.
- ☐ The links between particles in the metal are not strong.
- ☐ Water molecules interact with each other more strongly than they interact with the detergent.
- ☐ Dissolved substances change the nature of interaction between molecules in the solvent.
- ☐ The detergent weakens the interactions between water particles

(2) Here are six statements. Place them in pairs where one statement could have caused the other statement

(A) A boy went fishing at the lake
(B) He went with a friend
(C) He ate some green berries
(D) He caught two fish
(E) He was late home
(F) The next day he was very sick

Use letters to show which statement caused which statements

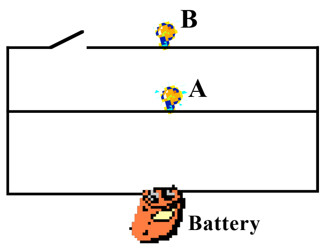
☐ caused ☐
☐ caused ☐
☐ caused ☐

(3) Imagine you lost your bicycle. You want to describe your bike to your friends so that they might find it. Which of the following statements would help find your bike?
(Tick as many as you wish)

My bicycle....

- ☐ Is red
- ☐ Was owned by my brother
- ☐ Has 10 speed gears and racing handle bars
- ☐ Was a birthday present
- ☐ Has rubber tyres
- ☐ Has a bent front mudguard

(4) Nora and Omar set up the circuit shown alongside. They predicted that, when they closed the switch, bulb B would light up and bulb A would be unaffected.



When they did close the switch, they found that bulb B DID light up. However, they noticed that bulb A ***dimmed*** very slightly.

Which of the following are possible explanations for what they observed?
Tick as many as you like.

- ☐ The wires have a small resistance.
- ☐ Bulb B is of lower resistance than A.
- ☐ The battery has some resistance.
- ☐ When bulb B lights, it reduces the current to bulb A.
- ☐ Bulb B takes voltage from bulb A.
- ☐ Bulb A is of lower resistance than B.
- ☐ Bulbs A and B are in parallel to each other.

(5) Mohammed has been studying global warming and wonders how scientists know what is actually the truth about global warming. His friend suggested several ways to find the answers. These are listed:

- A Read scientific books
- B Talk to experts like university professors
- C Carry out experiment to test the idea global warming
- D Collect as much information as possible about global warming
- E Assume global warming is true and act accordingly
- F Use intelligent guesswork
- G Look at information which has already been gathered through research
- H Accept what majority of people believe is true about global warming

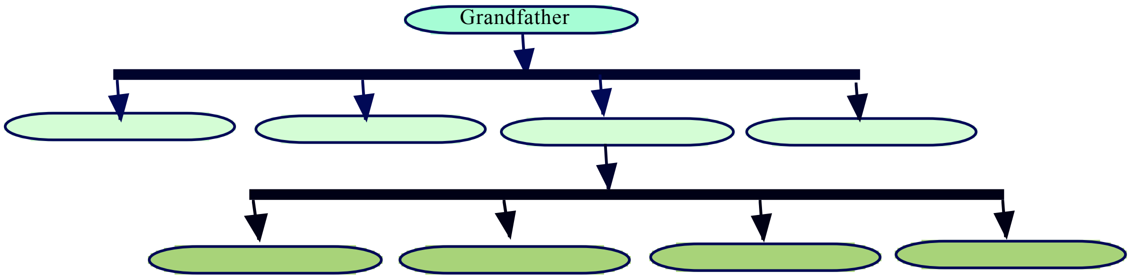
Arrange these suggested answers in order of their importance by placing the letters A,B,C...etc, in the boxes below. The letter which comes first is the most important and the letter which comes last is the least important for you.

Most important ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ Least important

(6) The table below gives information about a family, from grandfather to grandchildren. It is the year 2005.

Grandfather Still alive in the year 2005	**Aunt** 10 years older than uncle 2	**Uncle 1** 4 years younger than aunt
Father In 1965, he was same age as grandfather in 1932 and 4 years younger than Uncle 1	**Uncle 2** 2 years younger than father	**Sara** In 1995, her age was one-fifth the age of her Aunt
Ahmad In 1990, his age was half the age of Sara	**Abdulla** 2 years younger than Ahmad	**Maryam** 2 years younger than Abdulla

Use the information given in the table to complete the family tree diagram below, with grandfather at the top.



At the moment, it is impossible to calculate the age of the grandfather.

What ***other piece of information*** would you need about ***Maryam*** to work out the ***age of her grandfather*** in the year 2005?

....

.

Appendix

C

UNIVERSITY of GLASGOW

Centre for Science Education

This survey seeks to find out how you learn Physics. Your answers will not affect your Physics marks.

Your Name: ....

Name of school: ....

Grade: 10 Class.............

If you had to describe "a racing car" you could do it like this:

Quick	☑	☐	☐	☐	☐	☐	Slow	The positions of the ticks between the word pairs shows that you considered it s very quick, slightly more important than unimportant and quite dangerous.
Important	☐	☐	☑	☐	☐	☐	Unimportant	
Safe	☐	☐	☐	☐	☑	☐	Dangerous	

Use this method of ticking to answer the items 1 and 2

(1) I can learn physics better.....

on my own	☐	☐	☐	☐	☐	☐	in a group
through solving difficult activities	☐	☐	☐	☐	☐	☐	through solving easy activities
through reading physics books	☐	☐	☐	☐	☐	☐	without reading physics books
by doing physics experiments	☐	☐	☐	☐	☐	☐	without doing physics experiments
by relating it to events of daily life	☐	☐	☐	☐	☐	☐	by not relating it to events of daily life

(2) What are your general opinions about your ***physics lessons*** you did last course?

boring	☐	☐	☐	☐	☐	☐	interesting
easy to work out answers	☐	☐	☐	☐	☐	☐	difficult to work out answers
related physics to events of daily life	☐	☐	☐	☐	☐	☐	did not relate physics to events of daily life
made me like physics even more	☐	☐	☐	☐	☐	☐	made me hate science even more
improved my thinking skills	☐	☐	☐	☐	☐	☐	did not improve my thinking skills
enjoyed doing most of them	☐	☐	☐	☐	☐	☐	I hated doing most of them

(3) Think about your studies in physics

I understand things easily	☐	☐	☐	☐	☐	☐	I do not understand things easily
I have a good memory	☐	☐	☐	☐	☐	☐	I do not have a good memory
I learn quickly	☐	☐	☐	☐	☐	☐	I do not learn quickly
I am doing well in my studies	☐	☐	☐	☐	☐	☐	I am not doing well in my studies
I often forget what I learn	☐	☐	☐	☐	☐	☐	I often forget what I learn
I am sure I shall pass my examinations	☐	☐	☐	☐	☐	☐	I am not sure I shall pass my examinations
I feel I can succeed at most things I attempt	☐	☐	☐	☐	☐	☐	I do not feel I can succeed at most things I attempt
I like challenges	☐	☐	☐	☐	☐	☐	I do not like challenges
I enjoy learning in group	☐	☐	☐	☐	☐	☐	I do not enjoy learning in group
I like practical work in physics	☐	☐	☐	☐	☐	☐	I do not like practical work in physics
There is too much mathematics in physics	☐	☐	☐	☐	☐	☐	There is not too much mathematics in physics
My daily life is related to physics studies	☐	☐	☐	☐	☐	☐	My daily life is not related to physics studies
I like to solve problems in physics	☐	☐	☐	☐	☐	☐	I do not like to solve problems in physics
I prefer short answer exam question	☐	☐	☐	☐	☐	☐	I prefer exam question which allow me to express my ideas

Tick the boxes to show your opinions or your answer for question 4 - 5

(4) What are your feeling about working as a group?
(Tick the boxes to show your opinions)

(a) I found discussions boring ☐ ☐ ☐ ☐ ☐
(b) I enjoyed working with members of my group ☐ ☐ ☐ ☐ ☐
(c) Most of the ideas from other members of the group were not helpful ☐ ☐ ☐ ☐ ☐
(d) Most of the ideas came from one person ☐ ☐ ☐ ☐ ☐
(e) Working as a group made it easier for us to get answers ☐ ☐ ☐ ☐ ☐
(f) I did not respect ideas from others since they are always wrong ☐ ☐ ☐ ☐ ☐

(5) Show your opinion
Tick one box on each line.

I feel I am very good at my studies ☐ ☐ ☐ ☐ ☐
I feel that I am just as clever as others my own age ☐ ☐ ☐ ☐ ☐
I do not have a good imagination ☐ ☐ ☐ ☐ ☐
I take decisions quickly ☐ ☐ ☐ ☐ ☐
I am confident that I can finish my studies quickly ☐ ☐ ☐ ☐ ☐
I enjoy the challenge of a new problem in my studies ☐ ☐ ☐ ☐ ☐
I like to do things in new ways even if I am not sure of the best way ☐ ☐ ☐ ☐ ☐

(6) You may have studied topics like:

A Elasticity
B Hooke's Law
C Surface Tension
D Fluid Pressure
E Archimedes Principle
F Work
G Energy

Put these topics in order showing which you preferred most
Use the letters A to G.

☐ ☐ ☐ ☐ ☐ ☐ ☐
most preferred *least preferred*

UNIVERSITY *of* GLASGOW

University of Glasgow

Centre for Science Education

> This survey seeks to find out how you learn Physics.
> Your answers will not affect your Physics marks.

Your Name: ....

Name of school: ....

Grade: 11 Class..............

If you had to describe "a racing car" you could do it like this:

Quick	☑	☐	☐	☐	☐	☐	Slow
Important	☐	☐	☑	☐	☐	☐	Unimportant
Safe	☐	☐	☐	☐	☑	☐	Dangerous

The positions of the ticks between the word pairs shows that you considered it s very quick, slightly more important than unimportant and quite dangerous.

Use this method of ticking to answer the items 1 and 2

(1) I can learn physics better.....

on my own	☐	☐	☐	☐	☐	☐	in a group
through solving difficult activities	☐	☐	☐	☐	☐	☐	through solving easy activities
through reading physics books	☐	☐	☐	☐	☐	☐	without reading physics books
by doing physics experiments	☐	☐	☐	☐	☐	☐	without doing physics experiments
by relating it to events of daily life	☐	☐	☐	☐	☐	☐	by not relating it to events of daily life

(2) What are your general opinions about your ***physics lessons*** you did last course?

boring	☐	☐	☐	☐	☐	☐	interesting
easy to work out answers	☐	☐	☐	☐	☐	☐	difficult to work out answers
related physics to events of daily life	☐	☐	☐	☐	☐	☐	did not relate physics to events of daily life
made me like physics even more	☐	☐	☐	☐	☐	☐	made me hate science even more
improved my thinking skills	☐	☐	☐	☐	☐	☐	did not improve my thinking skills
enjoyed doing most of them	☐	☐	☐	☐	☐	☐	I hated doing most of them

(3) Think about your studies in physics

I understand things easily	☐	☐	☐	☐	☐	☐	I do not understand things easily
I have a good memory	☐	☐	☐	☐	☐	☐	I do not have a good memory
I learn quickly	☐	☐	☐	☐	☐	☐	I do not learn quickly
I am doing well in my studies	☐	☐	☐	☐	☐	☐	I am not doing well in my studies
I often forget what I learn	☐	☐	☐	☐	☐	☐	I often forget what I learn
I am sure I shall pass my examinations	☐	☐	☐	☐	☐	☐	I am not sure I shall pass my examinations
I feel I can succeed at most things I attempt	☐	☐	☐	☐	☐	☐	I do not feel I can succeed at most things I attempt
I like challenges	☐	☐	☐	☐	☐	☐	I do not like challenges
I enjoy learning in group	☐	☐	☐	☐	☐	☐	I do not enjoy learning in group
I like practical work in physics	☐	☐	☐	☐	☐	☐	I do not like practical work in physics
There is too much mathematics in physics	☐	☐	☐	☐	☐	☐	There is not too much mathematics in physics
My daily life is related to physics studies	☐	☐	☐	☐	☐	☐	My daily life is not related to physics studies
I like to solve problems in physics	☐	☐	☐	☐	☐	☐	I do not like to solve problems in physics
I prefer short answer exam question	☐	☐	☐	☐	☐	☐	I prefer exam question which allow me to express my ideas

Tick the boxes to show your opinions or your answer from question 4 - 5

(4) What are your feeling about working as a group?
(Tick the boxes to show your opinions)

(a) I found discussions boring ☐ ☐ ☐ ☐ ☐
(b) I enjoyed working with members of my group ☐ ☐ ☐ ☐ ☐
(c) Most of the ideas from other members of the group were not helpful ☐ ☐ ☐ ☐ ☐
(d) Most of the ideas came from one person ☐ ☐ ☐ ☐ ☐
(e) Working as a group made it easier for us to get answers ☐ ☐ ☐ ☐ ☐
(f) I did not respect ideas from others since they are always wrong ☐ ☐ ☐ ☐ ☐

(5) Show your opinion
Tick one box on each line.

(a) I feel I am very good at my studies ☐ ☐ ☐ ☐ ☐
(b) I feel that I am just as clever as others my own age ☐ ☐ ☐ ☐ ☐
(c) I do not have a good imagination ☐ ☐ ☐ ☐ ☐
(d) I take decisions quickly ☐ ☐ ☐ ☐ ☐
(e) am confident that I can finish my studies quickly ☐ ☐ ☐ ☐ ☐
(f) I enjoy the challenge of a new problem in my studies ☐ ☐ ☐ ☐ ☐
(g) like to do things in new ways even if I am not sure of the best way c☐ ☐ ☐ ☐ ☐

(6) You may have studied topics like:

A Vectors
B Linear Motion
C Newton's Laws
D Gravitational Forces
E Friction
F Moments of Force and Couple
G Uniform Circular Motion

Put these topics in order showing which you preferred most
Use the letters A to G.

☐ ☐ ☐ ☐ ☐ ☐ ☐
most preferred *least preferred*

UNIVERSITY of GLASGOW

University of Glasgow

Centre for Science Education

> This survey seeks to find out how you learn Physics.
> Your answers will not affect your Physics marks.

Your Name: ....

Name of school: ....

Grade: 12 Class..............

If you had to describe "a racing car" you could do it like this:

Quick	✓						Slow
Important			✓				Unimportant
Safe					✓		Dangerous

The positions of the ticks between the word pairs shows that you considered it s very quick, slightly more important than unimportant and quite dangerous.

Use this method of ticking to answer the items 1 and 2

(1) I can learn physics better.....

on my own	☐	☐	☐	☐	☐	☐	in a group
through solving difficult activities	☐	☐	☐	☐	☐	☐	through solving easy activities
through reading physics books	☐	☐	☐	☐	☐	☐	without reading physics books
by doing physics experiments	☐	☐	☐	☐	☐	☐	without doing physics experiments
by relating it to events of daily life	☐	☐	☐	☐	☐	☐	by not relating it to events of daily life

(2) What are your general opinions about your ***physics lessons*** you did last course?

boring	☐	☐	☐	☐	☐	☐	interesting
easy to work out answers	☐	☐	☐	☐	☐	☐	difficult to work out answers
related physics to events of daily life	☐	☐	☐	☐	☐	☐	did not relate physics to events of daily life
made me like physics even more	☐	☐	☐	☐	☐	☐	made me hate science even more
improved my thinking skills	☐	☐	☐	☐	☐	☐	did not improve my thinking skills
enjoyed doing most of them	☐	☐	☐	☐	☐	☐	I hated doing most of them

(3) Think about your studies in physics

I understand things easily	☐	☐	☐	☐	☐	☐	I do not understand things easily
I have a good memory	☐	☐	☐	☐	☐	☐	I do not have a good memory
I learn quickly	☐	☐	☐	☐	☐	☐	I do not learn quickly
I am doing well in my studies	☐	☐	☐	☐	☐	☐	I am not doing well in my studies
I often forget what I learn	☐	☐	☐	☐	☐	☐	I often forget what I learn
I am sure I shall pass my examinations	☐	☐	☐	☐	☐	☐	I am not sure I shall pass my examinations
I feel I can succeed at most things I attempt	☐	☐	☐	☐	☐	☐	I do not feel I can succeed at most things I attempt
I like challenges	☐	☐	☐	☐	☐	☐	I do not like challenges
I enjoy learning in group	☐	☐	☐	☐	☐	☐	I do not enjoy learning in group
I like practical work in physics	☐	☐	☐	☐	☐	☐	I do not like practical work in physics
There is too much mathematics in physics	☐	☐	☐	☐	☐	☐	There is not too much mathematics in physics
My daily life is related to physics studies	☐	☐	☐	☐	☐	☐	My daily life is not related to physics studies
I like to solve problems in physics	☐	☐	☐	☐	☐	☐	I do not like to solve problems in physics
I prefer short answer exam question	☐	☐	☐	☐	☐	☐	I prefer exam question which allow me to express my ideas

Tick the boxes to show your opinions or your answer from question 4 - 5

(4) What are your feeling about working as a group?
(Tick the boxes to show your opinions)

(a) I found discussions boring ☐ ☐ ☐ ☐ ☐
(b) I enjoyed working with members of my group ☐ ☐ ☐ ☐ ☐
(c) Most of the ideas from other members of the group were not helpful ☐ ☐ ☐ ☐ ☐
(d) Most of the ideas came from one person ☐ ☐ ☐ ☐ ☐
(e) Working as a group made it easier for us to get answers ☐ ☐ ☐ ☐ ☐
(f) I did not respect ideas from others since they are always wrong ☐ ☐ ☐ ☐ ☐

(5) Show your opinion
Tick one box on each line.

(a) I feel I am very good at my studies ☐ ☐ ☐ ☐ ☐
(b) I feel that I am just as clever as others my own age ☐ ☐ ☐ ☐ ☐
(c) I do not have a good imagination ☐ ☐ ☐ ☐ ☐
(d) I take decisions quickly ☐ ☐ ☐ ☐ ☐
(e) I am confident that I can finish my studies quickly ☐ ☐ ☐ ☐ ☐
(f) I enjoy the challenge of a new problem in my studies ☐ ☐ ☐ ☐ ☐
(g) I like to do things in new ways even if I am not sure of the best way ☐ ☐ ☐ ☐ ☐c

(6) You may have studied topics like:

A Streamline and flow characteristics
B Simple Harmonic Motion
C Refraction of waves
D Electromagnetic waves
E Interference of light
F Diffraction grating
G Geometrical Optics

Put these topics in order showing which you preferred most
Use the letters A to G.

☐ ☐ ☐ ☐ ☐ ☐ ☐
most preferred *least preferred*

Appendix

D

UNIVERSITY
of
GLASGOW

Thinking About Physics

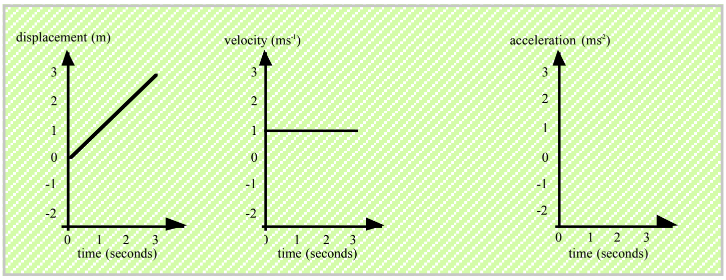
This test seeks to test your ability to understand some ideas in Physics.
The marks from this test will ***not*** *affect your school grades in any way.*
Most of the answers can be shown by drawing, writing a number or ticking a box.

Your Name ……………………………………………………………………………

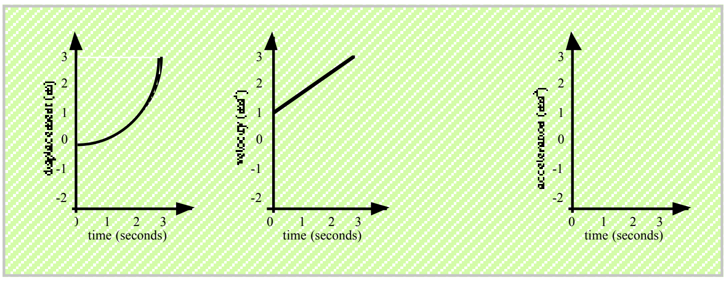
Name of school ……………………………………………………………………………

Grade .....10............ Class ………………

(1) The figure below shows the displacement-time graph and the velocity-time graph for a box moving in a factory.
Complete the third graph for the movement, showing the acceleration.



Another box moves in a different way.
Complete the third graph for the movement, showing its acceleration.



(2) When 100 ml water is cooled from 4˚C to 0˚C, it expands slightly.
Here are some statements about what is happening.
Select **ALL** the boxes which are **TRUE** *(use the numbers).*

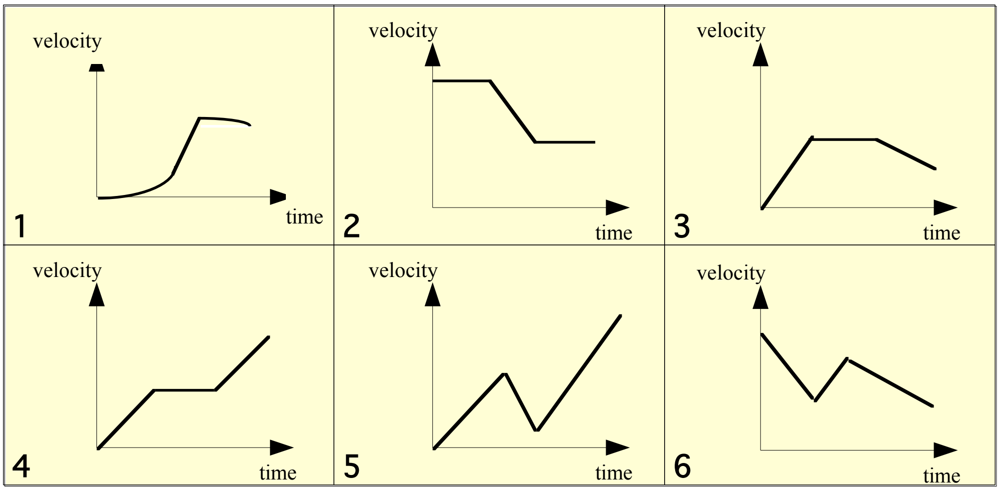
The density and the mass of the water decrease **1**	The volume increases and the density decreases **2**	The mass, volume and density are unaltered **3**
The volume of water increases **4**	The density and the mass are unaltered **5**	The volume and density increase **6**
The density increases but the mass stays the same **7**	The mass remains constant while the density decreases **8**	The density decreases, the volume iccreases and the mass stays the same **9**

Your answers: ....

(3) The displacement of a moving ball at different times is recorded in the following table:

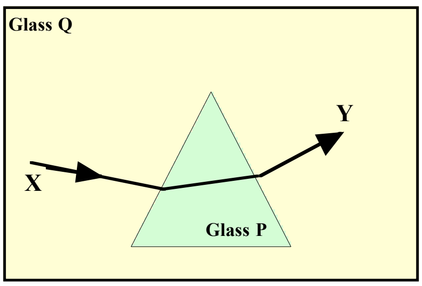
Time (s)	0	1	2	3	4	5	6	7	8	9	10	11
Displacement (m)	0	5	20	45	80	120	160	200	236	264	284	296

Which **ONE** of the following graphs could represent the movement (*use a number*)?



Answer: ....

(4) In an optics exhibit at a science fair, a ray of monochromatic light travels from X to Y through a block made from two *different* types of glass, P and Q as shown below.



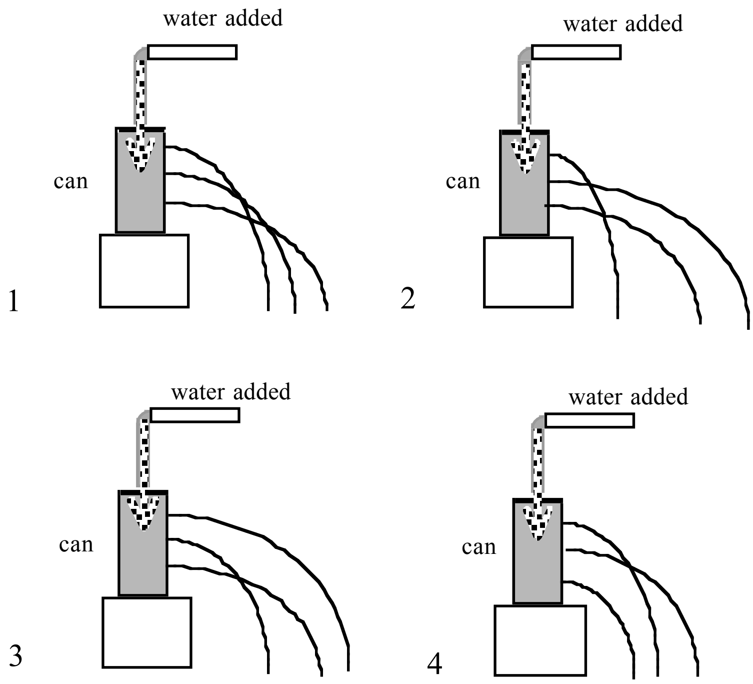
Look at each of the following statements and decide whether *each* is true (*underline to show your answer)*:

(A) Materials P and Q have different refractive indices
True ***Not true***

(B) Material P has a lower refractive index than material Q
True ***Not true***

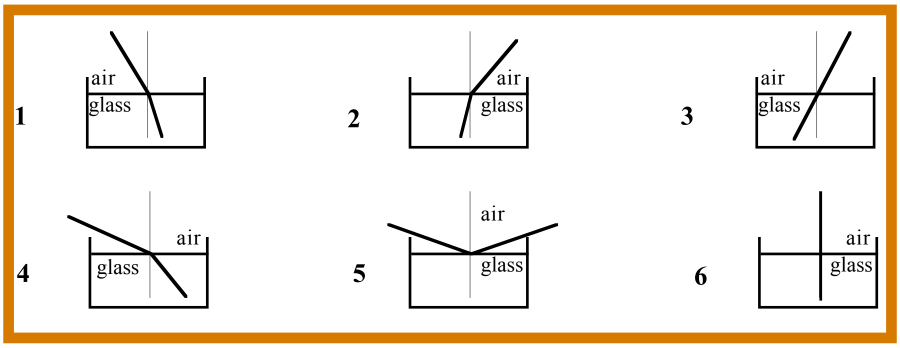
(C) The light is travelling faster in material P than in material Q
True ***Not true***

(5) A can is sitting on top of a block of wood. There are three holes down the side of the can. The can is filled with water. As water escapes through the holes, more water is added continuously. Which of the four pictures shows what you would expect to see?

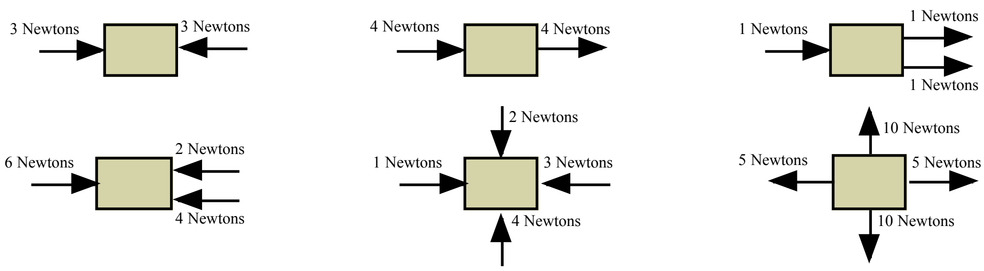


Your answer: ....

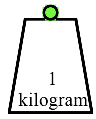
(6) A light beam travels *from* air towards a block of glass.
Which one of the following diagrams is impossible ? (*Put a ring round the answer*)



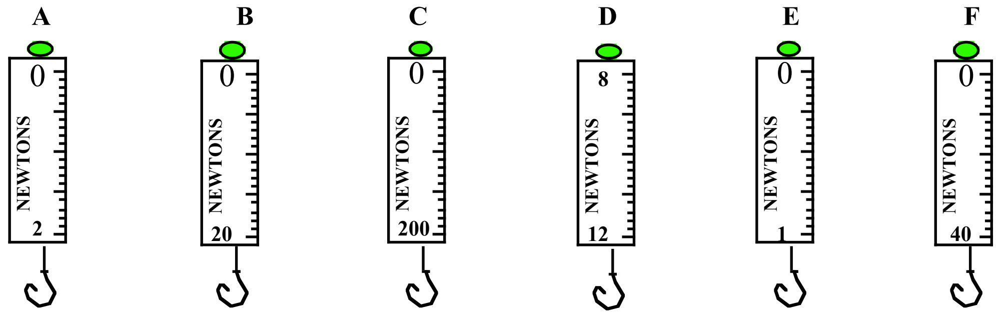
(7) Look at the six pictire below.
Put a ring round the pictures where the forces are balanced.



(8) A student carries out an experiment to measure the weight of a block.
The block is marked as having a mass of 1 kilogram as shown.

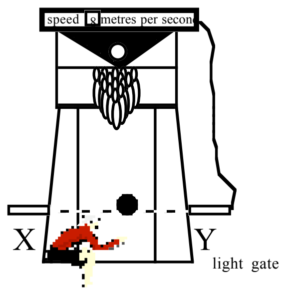


The student has to choose an appropriate balance. There are six balances available.
Select ***three*** balances would could be used and put them in preferred order.



First Choice: ....   Second choice: ....   Third Choice: ....

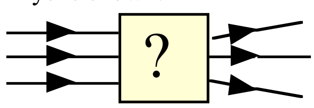
(9) At a bowling alley, the speed of a ball is measured as it starts to roll along a horizontal lane.
A light gate is positioned at X - Y. The light gate is connected to a computer.
The speed of the ball is measured using the light gate and the computer.
What two pieces of information does the computer need to calculate the speed of the ball?



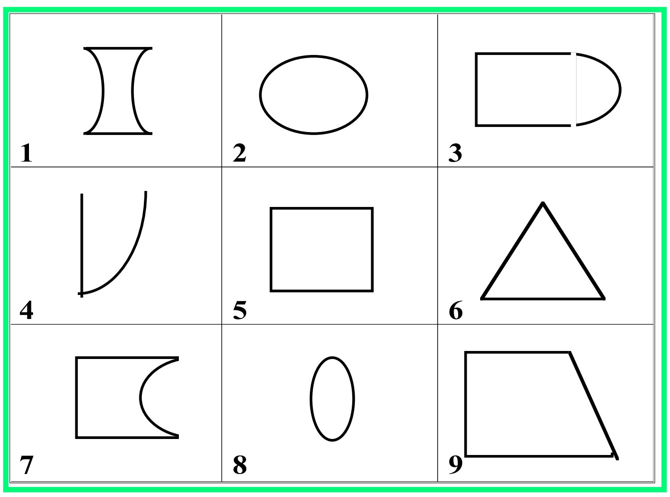
(1) ....

(2) ....

(10) Three parallel rays of light are passed through a glass shape that is placed under a card.
The effect of the glass shape on the rays is shown.

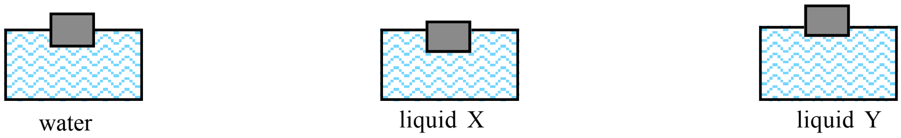


Which of the following could be the shape of the hidden glass shape ?
Choose *as many* as you think would work.



Possible answers:.........................

(11) An identical block floats on each of three liquids as shown:



Here are three statements:

(1) The density of the material of the block is less than the density of water.

(2) The density of liquid X is less than the density of water.

(3) The density of liquid X is greater than the density of liquid Y.

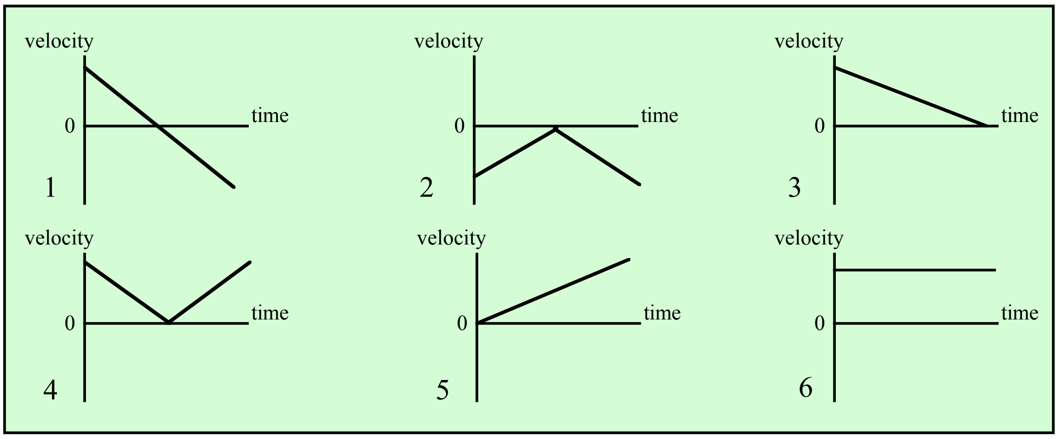
Which of the statements are correct?

(A) Both 1 and 2 ……….

(B) Both 1 and 3 ……….

(C) Both 2 and 3 ……….

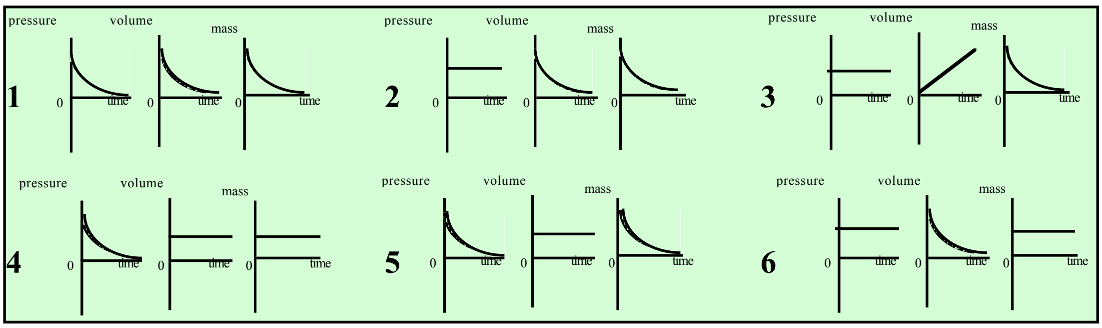
(12) Which of the following velocity-time graphs best describes a ball being thrown vertically into the air and returning to the thrower's hand?



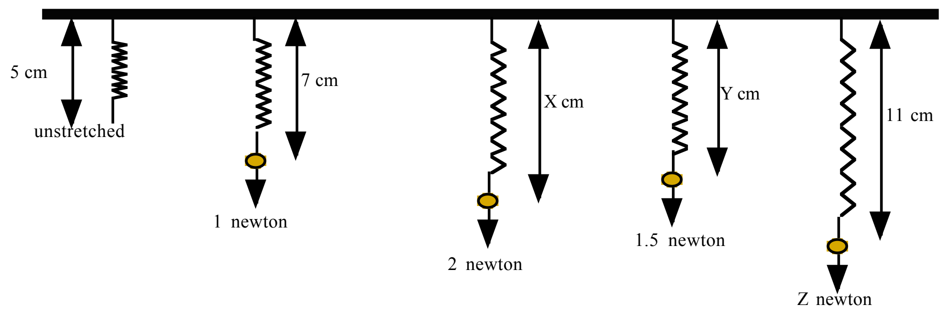
Your answer: ……..

(13) A rigid metal cylinder stores some compressed air.
Air is gradually released from the cylinder.
The temperature of the air remains constant

Which set of graphs shows how the pressure, the volume and the mass of the air *in the cylinder* change with time?

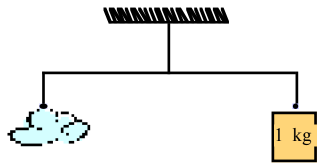


(14) The diagrams show a spring being stretched with different forces.
Find the missing values: X, Y and Z.

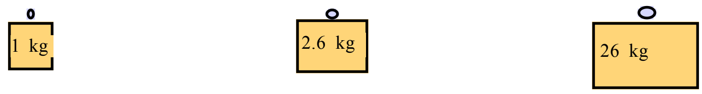


X = ……….. **Y** = ……….. **Z** = ………..

(15) The stone and the brass mass shown below are perfectly balanced on Earth.

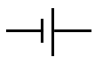
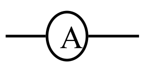
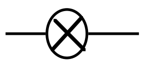
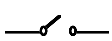
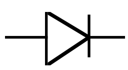
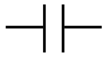
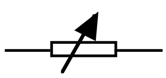


Which of these brass masses would need to be used to balance the stone on Jupiter?
Put a ring round the correct number.



1 **2** **3**

(16) The table below shows some symbols used when you draw circuits in physics.
Write the name for each symbol on the line in in each box.

 …………………………	 …………………………	 …………………………
 …………………………	 …………………………	 …………………………
 …………………………	 …………………………	…………………………

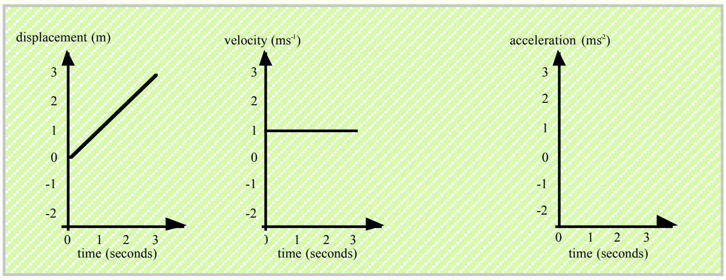
UNIVERSITY
of
GLASGOW

Thinking About Physics

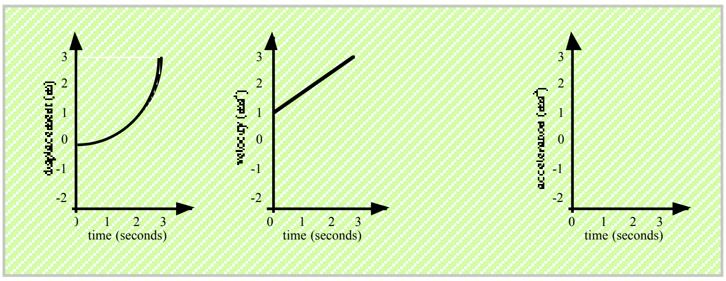
This test seeks to test your ability to understand some ideas in Physics.
*The marks from this test will **not** affect your school grades in any way.*
Most of the answers can be shown by drawing, writing a number or ticking a box.

Your Name ……………………………………………………………………………
Name of school ……………………………………………………………………………
Grade ....11 And 12.......... Class ………………

(1) The figure below shows the displacement-time graph and the velocity-time graph for a box moving in a factory.
Complete the third graph for the movement, showing the acceleration.



Another box moves in a different way.
Complete the third graph for the movement, showing its acceleration.



(2) When 100 ml water is cooled from 4˚C to 0˚C, it expands slightly.
Here are some statements about what is happening.
Select **ALL** the boxes which are **TRUE** *(use the numbers)*.

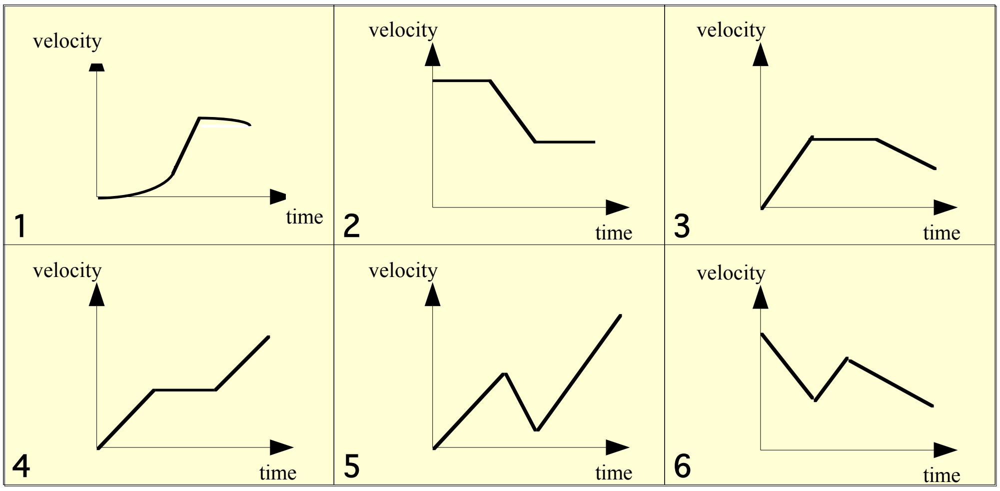
The density and the mass of the water decrease **1**	The volume increases and the density decreases **2**	The mass, volume and density are unaltered **3**
The volume of water increases **4**	The density and the mass are unaltered **5**	The volume and density increase **6**
The density increases but the mass stays the same **7**	The mass remains constant while the density decreases **8**	The density decreases, the volume icreases and the mass stays the same **9**

Your answers: ……………………………………………………

(3) The displacement of a moving ball at different times is recorded in the following table:

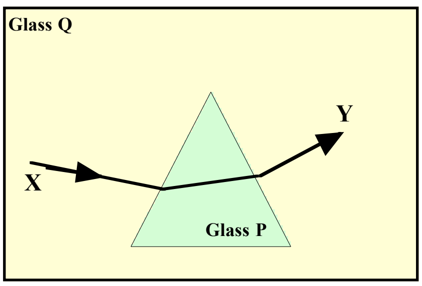
Time (s)	0	1	2	3	4	5	6	7	8	9	10	11
Displacement (m)	0	5	20	45	80	120	160	200	236	264	284	296

Which **<u>ONE</u>** of the following graphs could represent the movement (*use a number*)?



Answer: ……………..

(4) In an optics exhibit at a science fair, a ray of monochromatic light travels from X to Y through a block made from two *different* types of glass, P and Q as shown below.



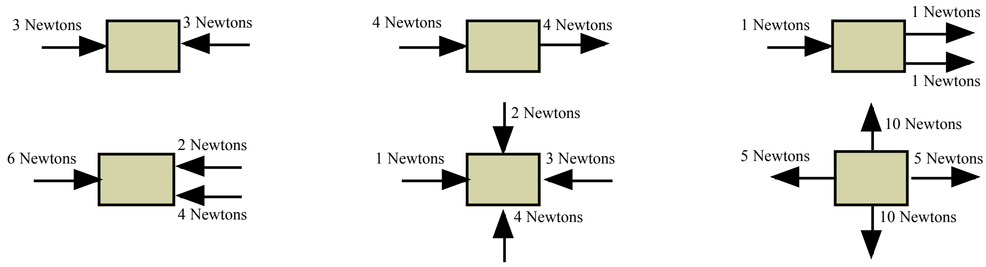
Look at each of the following statements and decide whether *each* is true (*underline to show your answer)*:

(A) Materials P and Q have different refractive indices
True ***Not true***

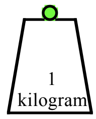
(B) Material P has a lower refractive index than material Q
True ***Not true***

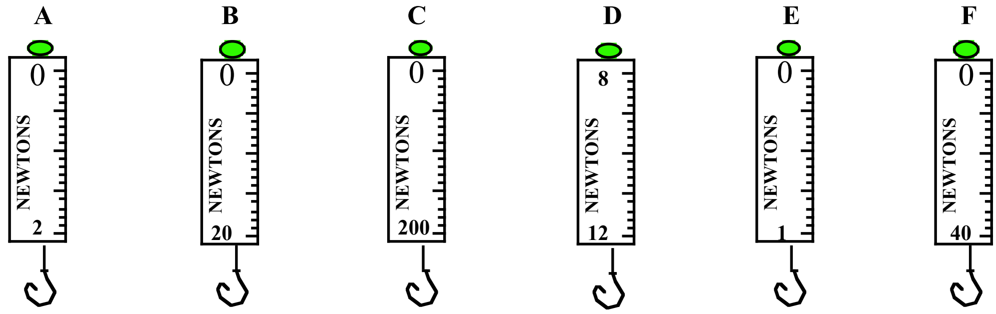
(C) The light is travelling faster in material P than in material Q
True ***Not true***

(5) Look at the six pictures below.
Put a ring round the pictures where the forces are balanced.



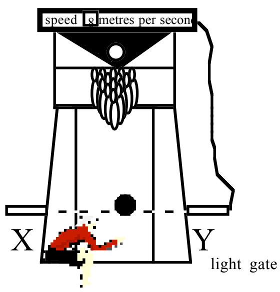
(6) A student carries out an experiment to measure the weight of a block.
The block is marked as having a mass of 1 kilogram as shown.
The student has to choose an appropriate balance. There are six balances available.
Select ***three*** balances would could be used and put them in preferred order.





First Choice: ....   Second choice: ....   Third Choice: ....

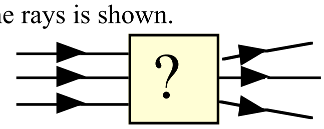
(7) At a bowling alley, the speed of a ball is measured as it starts to roll along a horizontal lane.
A light gate is positioned at X - Y. The light gate is connected to a computer.
The speed of the ball is measured using the light gate and the computer.
What two pieces of information does the computer need to calculate the speed of the ball?



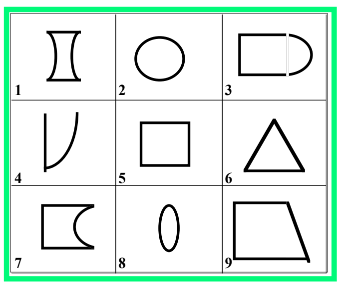
(1) ....

(2) ....

(8) Three parallel rays of light are passed through a glass shape that is placed under a card.
The effect of the glass shape on the rays is shown.

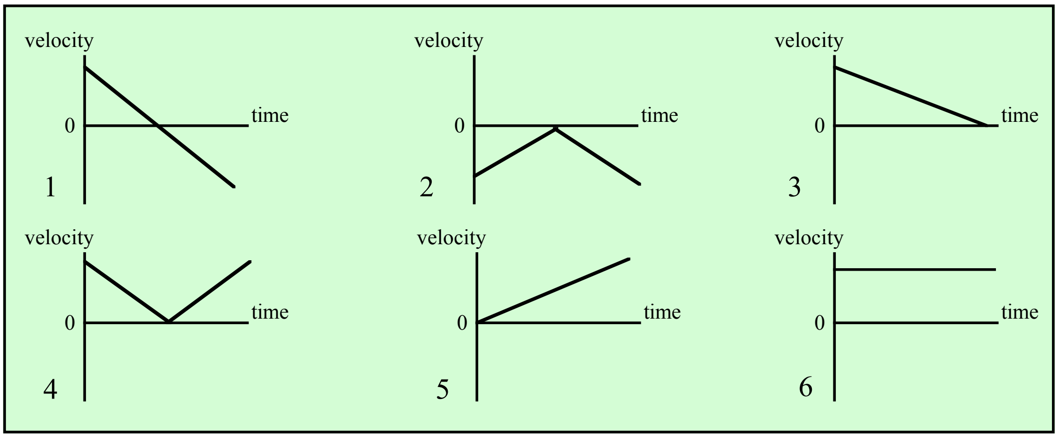


Which of the following could be the shape of the hidden glass shape ?
Choose *as many* as you think would work.



Possible answers:...

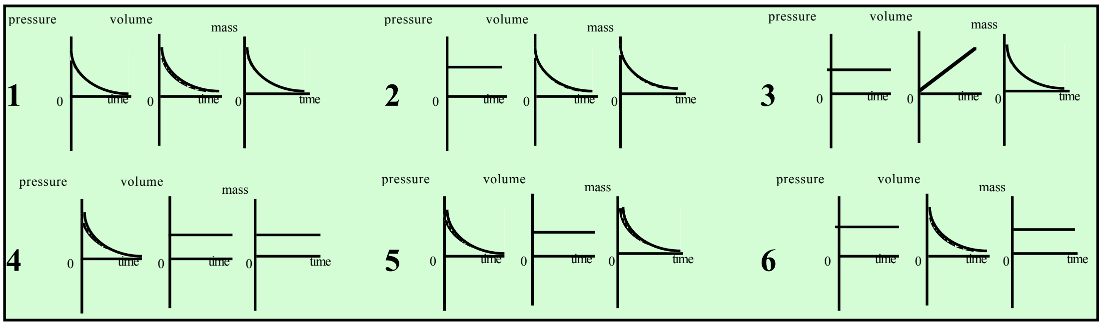
(9) Which of the following velocity-time graphs best describes a ball being thrown vertically into the air and returning to the thrower's hand?



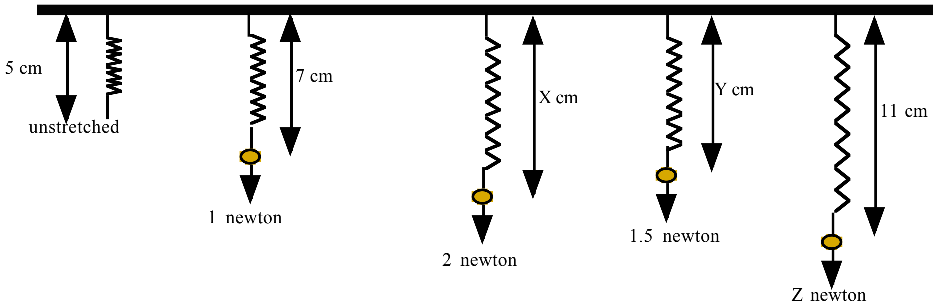
Your answer: ....

(10) A rigid metal cylinder stores some compressed air.
Air is gradually released from the cylinder.
The temperature of the air remains constant

Which set of graphs shows how the pressure, the volume and the mass of the air *in the cylinder* change with time?



(11) The diagrams show a spring being stretched with different forces.
Find the missing values: X, Y and Z.

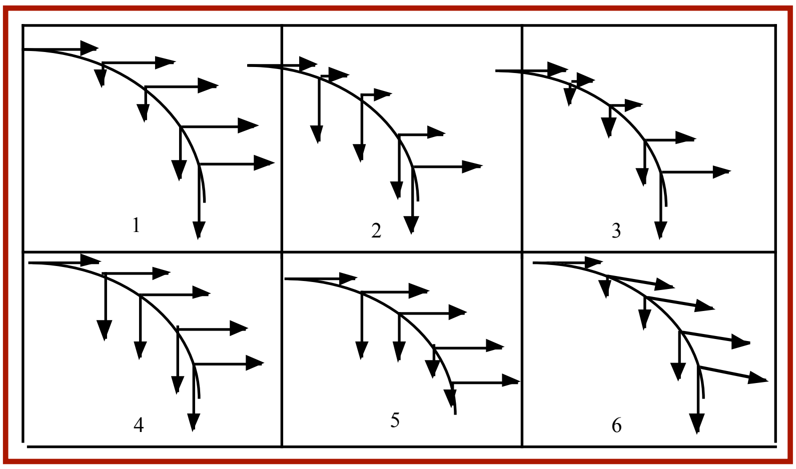


X = ... **Y** = ... **Z** = ...

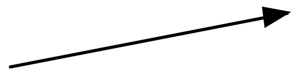
(12) The table below shows the result of an experiment moving a bar magnet and different coils to generate voltages. All the voltages have been measured correctly but the student forgot to link them to the right experiment. Put the values in the correct order in the table below.

	Experiment	Induced voltage (v)	The correct order
a	20 turns; N S; 1 m/s →; stationary	0	
b	40 turns; N S; stationary; ← 1 m/s	3.6	
c	40 turns; N S; 1 m/s →; ← 1 m/s	1.8	
d	20 turns; N S; 1 m/s →; 1 m/s →	5.4	
e	60 turns; N S; 1 m/s →; ← 1 m/s	0.9	

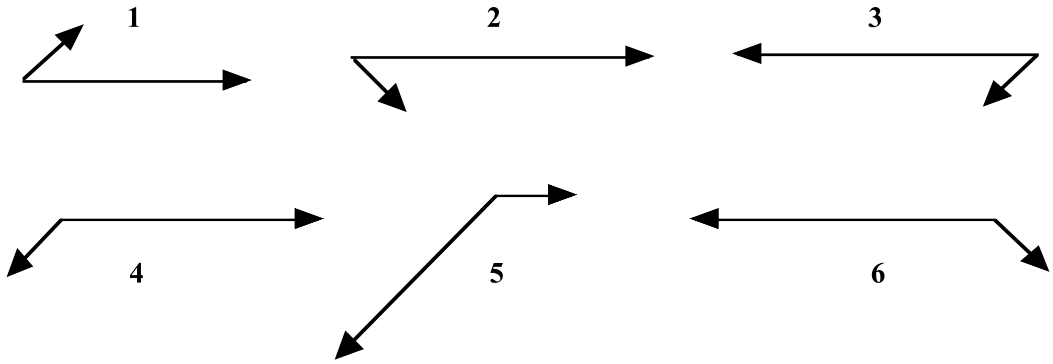
(13) Consider a space vehicle before it re-enters our atmosphere.
It is travelling horizontally at a constant speed.
Gravity pulls on the space vehicle in a vertically downwards direction.
The vehicle follows a projectile path.
Which of the figures below is right.



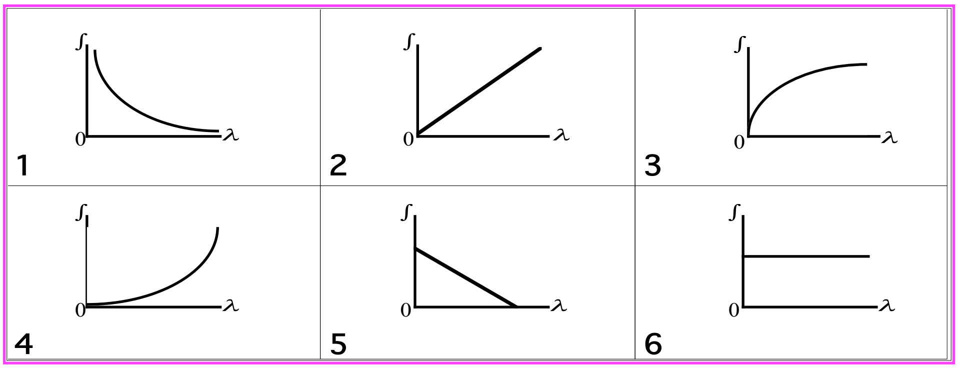
(14) The diagram below shows the resultant of two vectors:



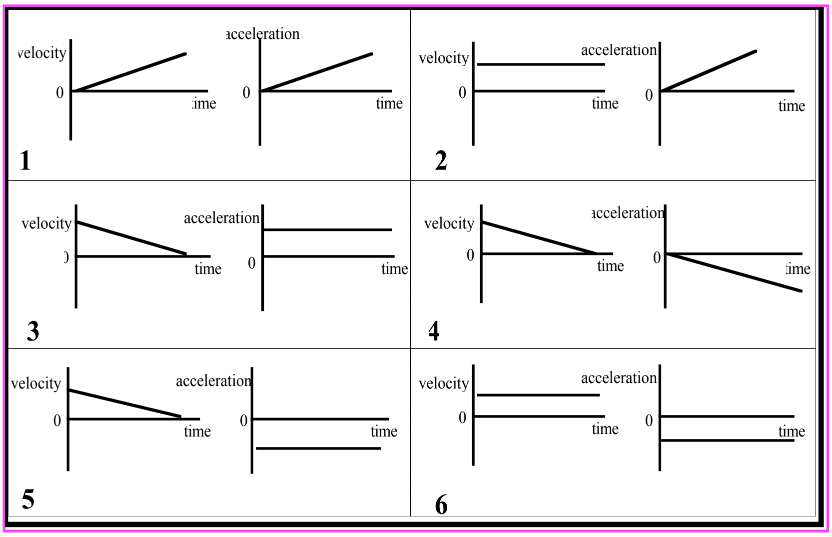
Which of the diagrams below shows the two vectors which could have produced the above resultant?



(15) Which graph shows the relationship between frequency ƒ and wavelength λ of photons of electromagnetic radiation?



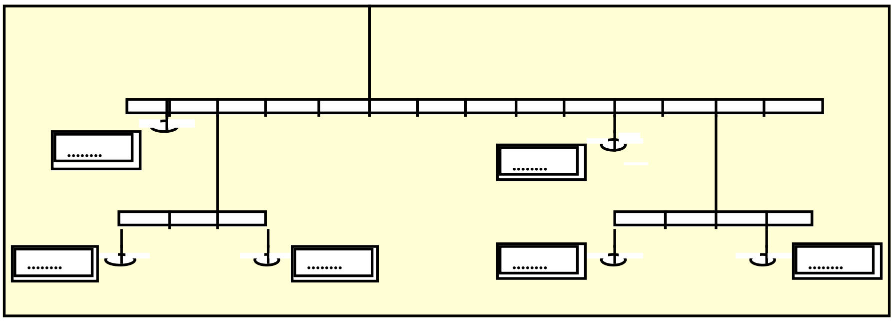
(16) The graphs in the boxes below represent the velocity and acceleration of a car moving in a straight line.



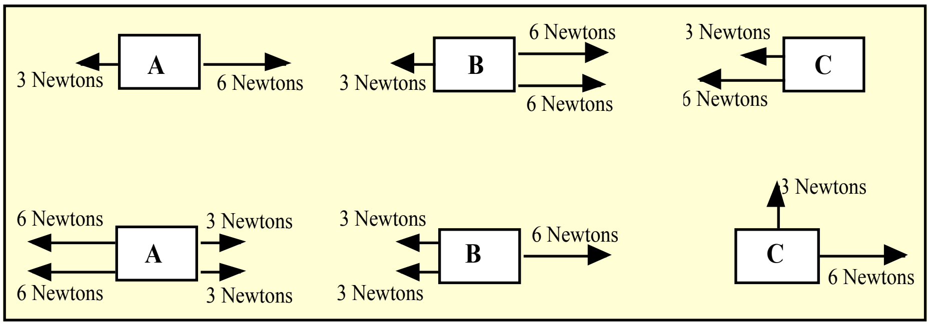
(a) Which box(es) contains a correct pair of graphs. ....

(b) Which box(es) show constant acceleration and changing velosity. ....

(17) You have six separate weights of 1g,2g,3g,4g,5g and 6g.
Place the six weights into the empty pans so that the scales balance.

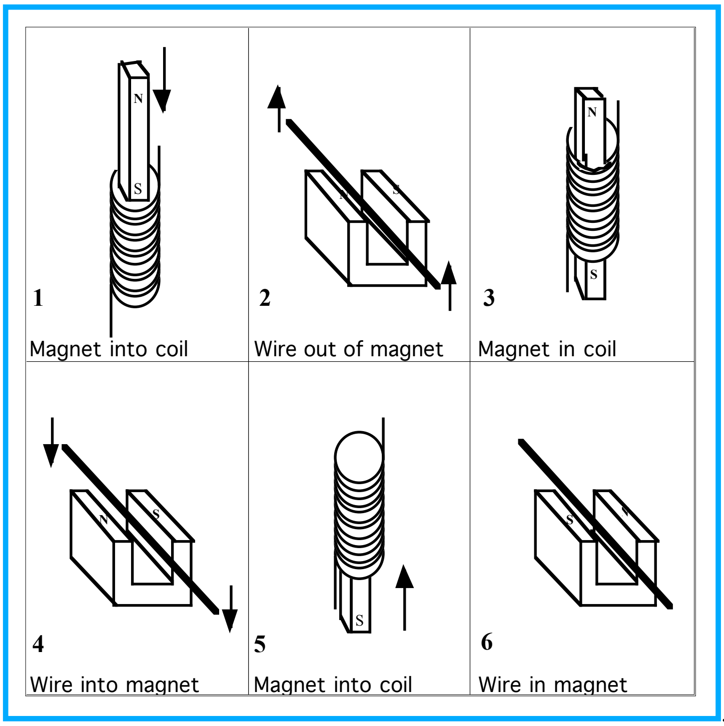


(18) The diagrams below show the forces acting on a number of moving objects.
Which object is moving at constant speed?

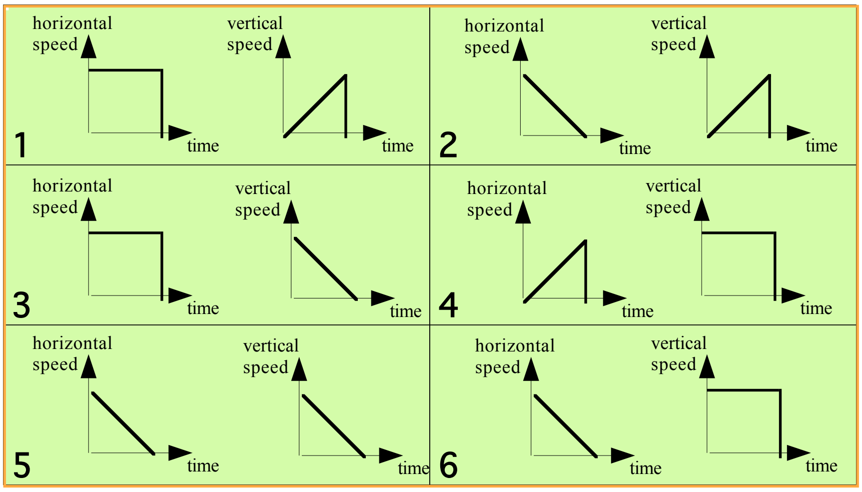


Answer: ....

(19) Look at the following diagrams which show magnets and electrical wires.

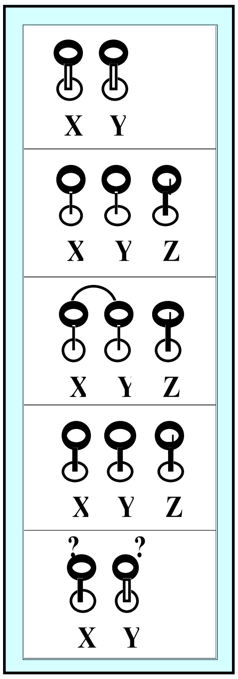


(20) A ball is kicked horizontally off the edge of cliff and lands in the sea .
Which pair of graphs shows the horizontal and vertical speeds of the ball during its flight?
The effect of air friction should be ignored.



Answer: ....

(21) The following experiment was carried out.



Two uncharged metal balls X and Y, stand on glass rods

A third ball, Z, carrying a positive charge is brought near the first two

A conducting wire is then run between X and Y

The wire is then removed

Ball Z is finally removed

When this is all done it is found that:
(Tick the correct answer)

☐ (A) Balls X and Y are still uncharged.
☐ (B) Balls X and Y are both charged positively.
☐ (C) Balls X and Y are both charged negatively.
☐ (D) Ball X is + and ball Y is -
☐ (E) Ball X is - and ball Y is +

Appendix E

A Question of Temperature

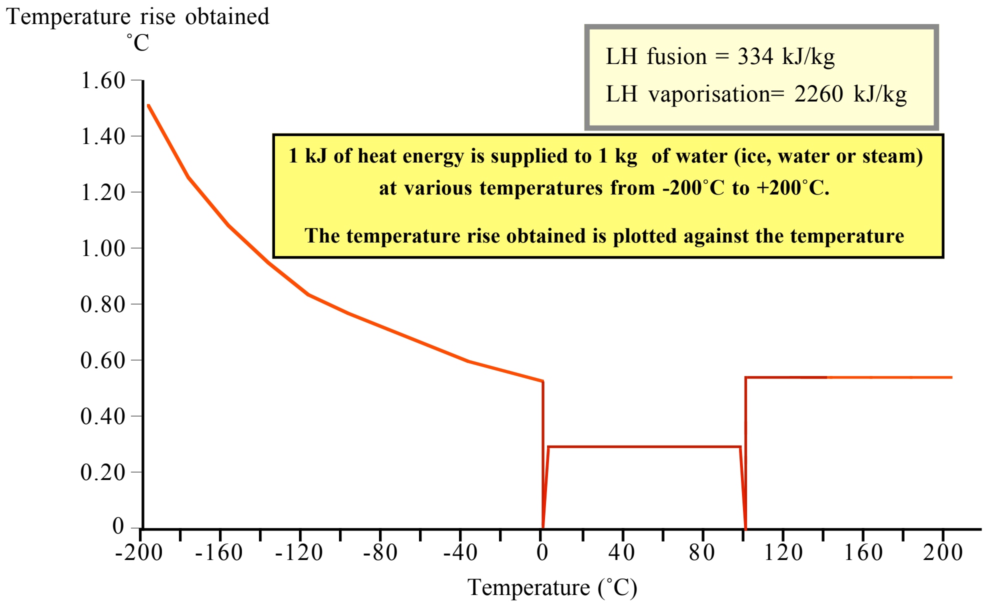
This is an imaginary experiment!!

In this experiment, some students carefully heated a block of ice, of mass 1g, from -200˚C until it melted and then on until it boiled and then on to a temperature of +200˚C. The pressure was constant at one atmosphere.

They found that, *for every Joule of Heat Energy supplied*, the temperature did ***not*** rise at a steady rate:

At -200˚C	1 Joule of Heat Energy raised the temperature by nearly 1.5˚C.
At 160˚C	1 Joule of Heat Energy raised the temperature by 0.5˚C.
At 60˚C	1 Joule of Heat Energy raised the temperature only by 0.25˚C.
At 0˚C	1 Joule of Heat Energy did not raise the temperature at all.
At 100˚C	1 Joule of Heat Energy did not raise the temperature at all.

They plotted their results and this is what they obtained:



Working as a group, discuss the following questions.

(1) Why does the line of the graph *drop to zero* for the temperature rise obtained at 0˚C and 100˚C.

....

....

(2) Offer some explanation why the line is lower *between* 0˚C and 100˚C (when the the water is in liquid form) than when less than 0˚C and when greater than 100˚C.

....

....

(3) Can you think of nay reason why the line is a falling curve when the water is in the form of ice but is a straight line when the water is in the form of steam?

....

....

A Hot Mystery

You will be working in a group of three.
Discuss answers to the questions below.
One of you can write down your agreed answers.

Part 1

The specific heat capacities of metals vary.

Here are some values:

Element	Spec Heat J/g/K
Aluminium	0.900
Copper	0.385
Gold	0.130
Iron	0.444
Lead	0.134
Magnesium	1.017
Silver	0.238
Tin	0.222
Zinc	0.389

Look at the table of values.
You are looking for any kind of pattern:
For example, aluminium has a much higher specific heat than, say, gold.
Magnesium is somewhat similar to aluminium while lead is nearer gold.

Can you see any pattern for all the values?

Write down the possible pattern you can see:

....

....

....

....

Do NOT turn over until told to do so

A Hot Mystery

Part 2

Did you spot that the 'light' metals have much higher specific heats than the 'heavy' ones. Thus, gold is the 'heaviest' metal and has the lowest specific heat capacity.

Let us look at more data:

Element	**Spec Heat J/g/K**
Aluminium	0.900
Calcium	0.653
Copper	0.385
Gold	0.130
Iron	0.444
Lead	0.134
Lithium	3.556
Magnesium	1.017
Manganese	0.481
Nickel	0.444
Silver	0.238
Tin	0.222
Zinc	0.389
Mercury	0.138

As a group, discuss:

(a) Is your pattern still true for metals?
(b) Is it true for all elements?
(c) What further information do you need ?

Do NOT turn over until told to do so

A Hot Mystery

Part 3

Alongside is information about more of the elements.

Element	Spec Heat J/g/K
Aluminium	0.900
Calcium	0.653
Copper	0.385
Gold	0.130
Iron	0.444
Lead	0.134
Lithium	3.556
Magnesium	1.017
Manganese	0.481
Nickel	0.444
Silver	0.238
Tin	0.222
Zinc	0.389
Mercury	0.138
Krypton	0.247
Bromine	0.226
Chlorine	0.477
Helium	5.188
Hydrogen	14.267
Iodine	0.142
Nitrogen	1.042
Oxygen	0.916
Phosphorus	0.669
Silicon	0.703
Sulphur	0.732

As a group:

(a) Look at the data.
Is your idea still correct?

An idea like this is known as a *hypothesis*.

A hypothesis is an attempt to make a pattern or explanation for some data.

Science then tries to look at the pattern or explanation and test if it is true.

(b) You have used the idea of 'light' and 'heavy' elements rather vaguely.

Can you test the idea using numbers?
Is there any way to get a number to show the weight of the elements or some other measure of their 'size'?

Write down your agreed ideas here:

....

....

....

....

....

Do NOT turn over until told to do so

A Hot Mystery

Part 4

There are many possibilities.

Did you think of:

Atomic Mass
Atomic Number
Atomic size (like the radius of an atom)
Density

Now let us try them all!

Element	Spec Heat cal/g/K	Spec Heat J/g/K	Atomic Mass	Atomic Number	Atomic Radius	Density g/cm3
Aluminium	0.215	0.900	27	13	143	2.6980
Calcium	0.156	0.653	40	20	197	1.5500
Copper	0.092	0.385	64	29	128	8.9600
Gold	0.031	0.130	197	79	146	19.3200
Iron	0.106	0.444	56	26	126	7.8740
Lead	0.032	0.134	207	82	171	11.8500
Lithium	0.850	3.556	7	3	155	0.5340
Magnesium	0.243	1.017	24	12	160	1.7380
Manganese	0.115	0.481	55	25	135	7.4400
Nickel	0.106	0.444	59	28	124	8.9020
Silver	0.057	0.238	108	47	144	10.5000
Tin	0.053	0.222	119	50	162	7.3100
Zinc	0.093	0.389	65	30	138	7.1330
Mercury	0.033	0.138	201.0	80.0	160	13.5460
Krypton	0.059	0.247	84	36	103	0.0037
Bromine	0.054	0.226	80	35	112	3.1220
Chlorine	0.114	0.477	35.5	17	97	0.0032
Helium	1.240	5.188	4	2	32	0.0002
Hydrogen	3.410	14.267	1	1	37	0.0001
Iodine	0.142	0.594	127	53	132	4.9300
Nitrogen	0.249	1.042	14	7	92	0.0012
Oxygen	0.219	0.916	16	8	65	0.0014
Phosphorus	0.160	0.669	31	15	128	1.8200
Silicon	0.168	0.703	28	14	132	2.3290
Sulphur	0.175	0.732	32	16	127	2.0700

As a group:

(a) Can you see which of the four things is related to the specific heat capacity ?
(b) Discuss how you might be more sure.

....

....

....

Do NOT turn over until told to do so

A Hot Mystery

Part 5

Did you think of this ??

If the specific heat capacity decreases as the atomic mass, the atomic number, the atomic radius or the density increases, then how about multiplying the specific heat by each in turn to see which gives closest to a constant value.

Here are the data:

Element	Spec Heat J/g/K	Atomic Mass	Atomic Number	Atomic Radius	Density	Sp Heat X At Mass	Sp Heat X At Number	Sp Heat X Radius	Sp Heat X Density
Aluminium	0.900	27	13	143	2.6980	24.3	11.7	128.6	2.427
Calcium	0.653	40	20	197	1.5500	26.1	13.1	128.6	1.012
Copper	0.385	64	29	128	8.9600	24.6	11.2	49.3	3.449
Gold	0.130	197	79	146	19.3200	25.6	10.2	18.9	2.506
Iron	0.444	56	26	126	7.8740	24.8	11.5	55.9	3.492
Lead	0.134	207	82	171	11.8500	27.7	11.0	22.9	1.587
Lithium	3.556	7	3	155	0.5340	24.9	10.7	551.2	1.899
Magnesium	1.017	24	12	160	1.7380	24.4	12.2	162.7	1.767
Manganese	0.481	55	25	135	7.4400	26.5	12.0	65.0	3.580
Nickel	0.444	59	28	124	8.9020	26.2	12.4	55.0	3.948
Silver	0.238	108	47	144	10.5000	25.8	11.2	34.3	2.504
Tin	0.222	119	50	162	7.3100	26.4	11.1	35.9	1.621
Zinc	0.389	65	30	138	7.1330	25.3	11.7	53.7	2.776
Mercury	0.138	201.0	80.0	160	13.5460	27.8	11.0	22.1	1.870
Krypton	0.247	84	36	103	0.0037	20.7	8.9	25.4	0.001
Bromine	0.226	80	35	112	3.1220	18.1	7.9	25.3	0.705
Chlorine	0.477	35.5	17	97	0.0032	16.9	8.1	46.3	0.002
Helium	5.188	4	2	32	0.0002	20.8	10.4	166.0	0.001
Hydrogen	14.267	1	1	37	0.0001	14.3	14.3	527.9	0.001
Iodine	0.142	127	53	132	4.9300	18.0	7.5	18.7	0.700
Nitrogen	1.042	14	7	92	0.0012	14.6	7.3	95.8	0.001
Oxygen	0.916	16	8	65	0.0014	14.7	7.3	59.6	0.001
Phosphorus	0.669	31	15	128	1.8200	20.8	10.0	85.7	1.218
Silicon	0.703	28	14	132	2.3290	19.7	9.8	92.8	1.637

As a group, look at the last four columns of the table.

Can you see the best pattern?
Is your hypothesis still true?

Write down your agreed conclusions:

....

....

.

Do NOT turn over until told to do so

A Hot Mystery

Part 6

As a group, try to think of an explanation for the pattern you have observed.

Write down you agreed conclusions below.

....

....

....

....

....

....

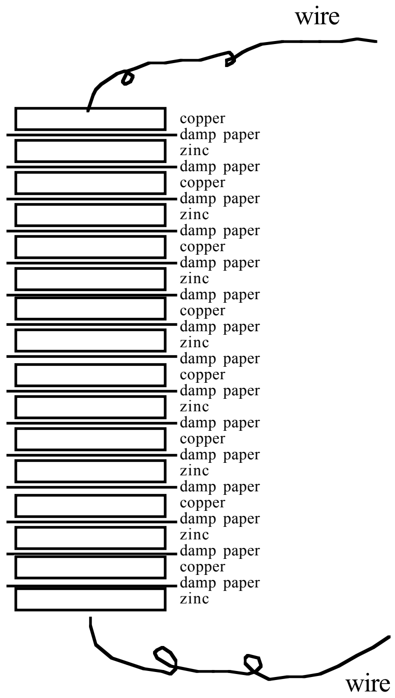
The Puzzle of Electricity

You will be working in a group of three.
Discuss answers to the questions below.
One of you can write down your agreed answers.

You may have seen sparks with electricity and thought of this in terms of electrical charge jumping across an air gap.

You may have seen a Van de Graaf generator and seen hair standing up on end. Perhaps you saw this as electrical charges repelling each other.

Just over 200 years ago, little was known about electrical charge. One day, an Italian called Volta built a simple primitive battery. It looked at bit like this:



Imagine you lived in Volta's time.

Remember: no one really understood much about charge or electricity.

Do NOT turn over until told to do so

Your First Task

Discuss the following questions, ***as a group***:

In Volta's apparatus, there is a wire coming from the top and one coming from the bottom.

He found that the the two wires (both made of the same metal) behaved in different ways

(a) Discuss how you might show that the effect of the lower wire in Volta's battery was behaving differently from the effect of the upper wire.
(Write your agreed answers in the space below)

....

....

....

....

(b) What is really meant by positive and negative charge?
What does your experiment really tell you?
(Write your agreed answers in the space below)

....

....

....

....

Do NOT turn over until told to do so

Your Second Task

Many adults claim they do not understand electricity.

(i) As a group, work out an experiment to ***show*** that there are two kinds of charges. You may have to invent apparatus.

(ii) Develop some way of showing the different effects of the two kinds of charges.

(iii) The negative charges can move fairly easily but the positive charges do not move easily.
Explain why it is so ***difficult*** to show that this is true?

(iv) Can you think of a way to suggest that the negative charges move more easily?

(Write your agreed answers in the space below)

....

....

....

....

....

....

....

....

....

....

....

....

Do NOT turn over until told to do so

Water - a Unique Substance

Look at the questions below and try to answer them on your own.

Part 1

(1) Pure water has a specific heat capacity of 4.18 $kJkg^{-1}K^{-1}$.
Iron of a certain quality has a specific heat capacity of 0.418 $kJkg^{-1}K^{-1}$.
The latent heat of fusion of ice is 334 $kJkg^{-1}$.
The latent heat of vaporisation of water is 2260 $kJkg^{-1}$.

Look at the table below and answer the questions which follow, using the letters provided.
You may use any box as often as you wish.

50g pure water heated from 0°C to 50°C	100g pure ice melting completely at a constant temperature	500g iron heated from 0°C to 50°C
200g pure ice melting completely at a constant temperature	100g pure water freeezing to ice at a constant temperature.	50g iron heated from 0°C to 50°C
500g pure water heated from 0°C to 50°C	100g pure water boiling completely to stam at a constant temperature	5000g iron heated from 0°C to 50°C
50g pure water heated from 25°C to 75°C	500g iron heated from 25°C to 75°C	500g pure water cooled from 50°C to 0°C

Select ***all*** the boxes which:

(a) Take place at the same temperature as box B. ....

(b) Involve the same energy change as box A. ....

(c) Involve the same energy change as box H. ....

(d) Involve the highest energy change. ....

(e) Involve the lowest termperature at the end. ....

Now compare your answers with other students in your group.
Discuss any differences you have found.

Do NOT turn over until told to do so

Part 2

You will be working in a group of three.
Discuss answers to the questions below.
One of you can write down your agreed answers.

Here is information about three problems:

(a) Why is that touching ice at 0˚C feels colder than touching iron at 0˚C?

....

....

(b) 1kg water at 50˚C possesses more heat energy than 1kg of iron at 50˚C. Is this true?

....

....

(c) It is estimated that over 70% of the earth's surface is covered by ocean, making approximately 1370 cubic kilometres of water.

(i) Calculate roughly the mass of water in the oceans in kg.

(ii) If global warming raise the average sea temperature by 0.5˚C, calculate the extra amount of heat energy stored in the oceans of the world.

Do NOT turn over until told to do so

Part 3

(d) It is easy to show that heat energy in water can be converted to kinetic energy. This is done by heating water to form steam, and letting the steam drive a turbine, as in a electricity power station.

It is ***not*** so easy to show that kinetic energy in water can be converted back in heat energy.

As a group discuss how you might try to do this so that a 15 year old school pupil would understand it. You can use diagrams if you wish to show your method. Try to estimate the amount of heat energy which would come from the mechanical energy to make sure that you can detect it.

When you worked out a method, one member of your group can write down your agreed procedures so that the 15 year school pupil can carry out the experiment safely.

The Big Challenge

Design and Experiment to Weigh Atoms !!

Sounds Impossible ??

Let's start at the beginning

You will be working in a group of three.
Discuss answers to the questions below.
One of you can write down your agreed answers.

Part 1

First Thoughts

What do you think atoms will weigh - just approximately?
Discuss this in your group

Have a guess:
Tick one box

☐	Roughly	10^{-3}g	(milligrams)
☐	Roughly	10^{-6}g	(micrograms)
☐	Roughly	10^{-9}g	(nanograms)
☐	Roughly	10^{-12}g	(picograms)
☐	Roughly	10^{-18}g	(attograms)
☐	Roughly	10^{-24}g	

How can we find out?

Here is one piece of information: in 5 cm^3 water (a teaspoonful), there are approximately 5×10^{23} atoms in the water molecules.

Use this information to estimate the kind of weight atoms might have

When you discuss this, tick your agreed choice:

10^{-3}g 10^{-6}g 10^{-9}g 10^{-12}g 10^{-18}g 10^{-24}g 10^{-30}g

Part 2

How did you get on?

Atoms must have weights like 10^{-23} or perhaps 10^{-22} grams.

Was your estimate something like this?

We still have the task: ***design an experiment to weigh atoms***.

However, we must sort out two ideas first. There are two words which cause confusion:

Mass: The amount of matter present.
Weight: The downward force an object exerts under gravity

Just to confuse things: usually, we find the mass of something by weighing the object!!

It is NOT going to be easy to weigh atoms - they are far too small.

Can we try it the other way: ***can we try to measure their mass instead?***

Here is a task to try:

Using the symbol 'm', write down as many formulae as you can from your knowledge of physics which involve mass. Remember: *do it as a group.*

Here is one to start:

$F = ma$ *(the equation which allows us to relate mass to weight)*

Part 3

You may have equations like:

$$F = ma$$
$$m_1v_1 = m_2v_2$$
$$KE = 1/2\ mv^2$$
$$PE = mgh$$

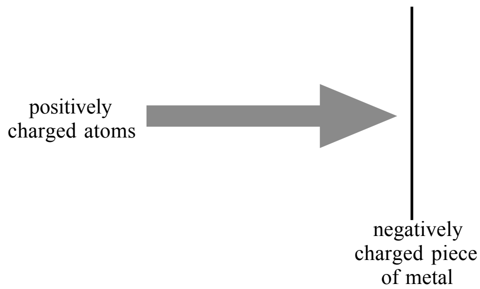
All these equations involve things like forces, acceleration or movement.

Of course, atoms can move around a lot and at great speeds. In gasses, the particles are flying around at enormous speeds but the movement is random. How might you arrange things so that we can make atoms in gases all move in the same direction?

Write down your agreed thoughts on this?

Part 4

Do you think of giving the particles an electrical charge and then attracting them in one direction. That would make the individual atoms all move in the same direction.



Perhaps we can measure the movement in some way and then work backwards to find the mass.

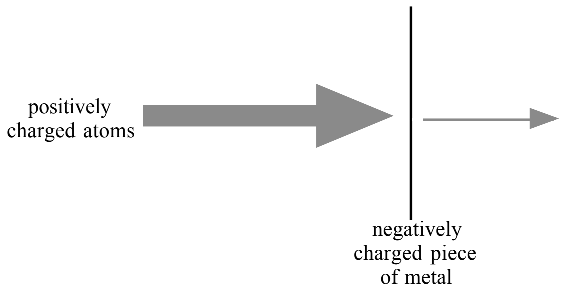
Discuss any ideas for doing this.
(Write down your agreed ideas below).

Part 5

Here is a clever way forward.

Suppose you make a tiny hole in the metal plate which is charged negatively. The stream of positive charges will accelerate towards the negatively charged plate.

Most will land on the plate but a tiny beam of the positively charged particles will pass straight through.



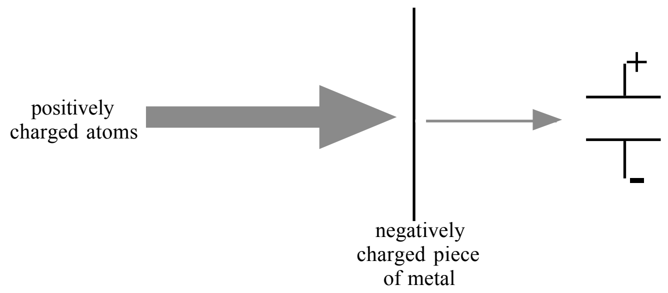
Can you think of anything you could do to this tiny beam of fast moving positively charged particles?

Will this depend on their mass in any way ?
(Write down your agreed ideas below)

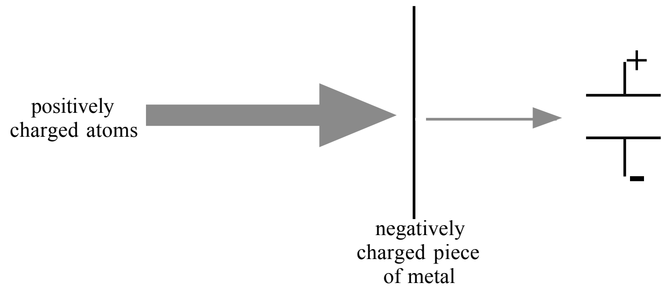
Part 6

Did you think of using a magnetic or electrical field?

Either will deflect the narrow beam of positively charged particles.

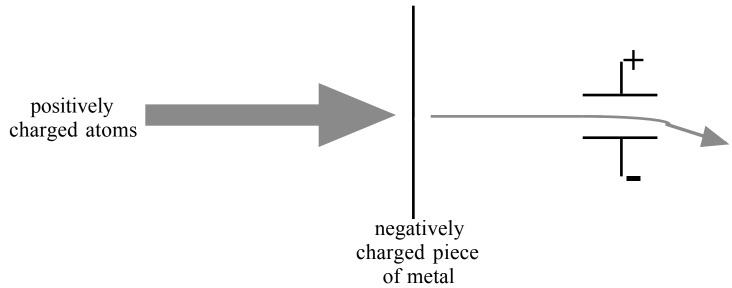


Draw in below what you think would happen.



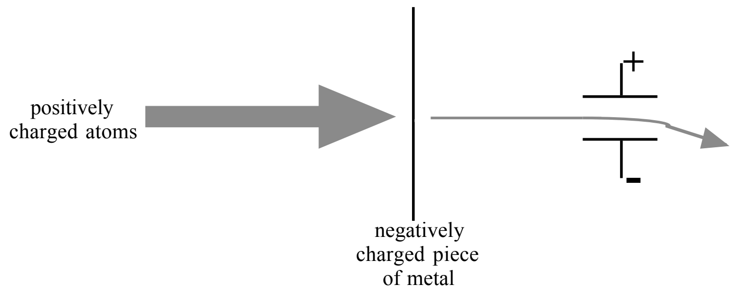
Part 7

If the positively charged particles were moving very fast, you might have a result like this:



Now imagine atoms of different masses.
All the atoms have the same positive charge.
They are all moving *very fast* between the two plates, one charged positively, the other charged negatively.

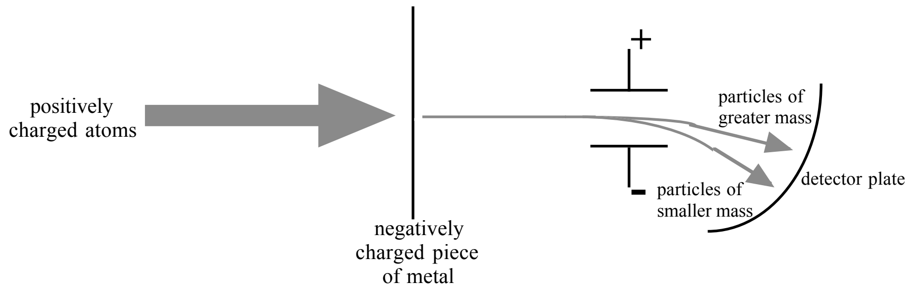
What would you expect to see?
Draw it on the diagram below



The Final Outcome

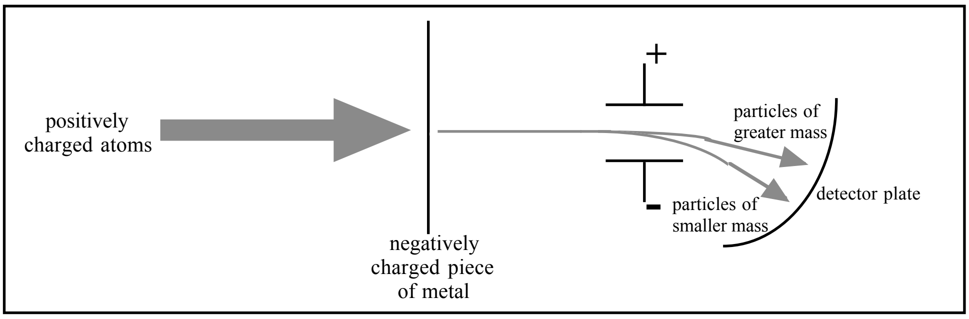
Here is the picture of what your experiment might look like. The particles of lower mass would be deflected more as they have less mass. The amount of deflection can be measured by some kind of detection plate.

Originally, this was like a photographic plate but, today, the detector is a series of electrical circuits. When particles land on the end of a circuit, a tiny current is produced and this is then amplified.



The equipment is known as a 'mass spectrometer' and it is vital for measuring the mass of tiny particles like atoms and small molecules. To make it work, everything is in a tube from which all the air has been removed using a pump. The negatively charged plate is often at very high voltage (maybe around 2000 volts). There are many refinements which are used but this shows the basic principle only.

Now you have developed a way to measure the mass of atoms!!



However, can you see any other problems?
(Discuss this and write down your agreed answers below)

……

……

……

Centre for Science Education
Physics Thinking Units
Teacher's Guide

There are five units in this set. Their titles are:

(1)	*A Question of Temperature*	How some experimental data can be interpreted
(2)	*A Hot Mystery*	The way data can be interpreted in relation to specific heat capacity
(3)	*The Puzzle of Electricity*	How can experiments be devised to show some basic ideas in electricity
(4)	*Water - A Unique Substance*	Heat and temperature. devising an experiment
(5)	*The Big Challenge*	How to invent an apparatus to 'weigh' atoms.

The units are not designed to teach Physics but seek to allow pupils to think about the nature and place of experimentation in relation to the development of ideas in Physics.

They all involve pupils working in small groups of three. When using any of these units, form your class into groups of three (an occasional four is fine if numbers are not a multiple of three). Allow the groups to work at the problems *on their own*. Do not intervene unless a group is completely stuck and, then, only offer some hints to re-start them. The production of 'right' answers is not as important as the discussion of ideas leading to 'possible' answers.

(1) ***A Question of Temperature***

(a) Form groups of three
(b) Give out a copy of the unit to each pupil
(c) Encourage them to talk to each other and not to try to work individually.
(d) Likely answers:

Question (1) They should come with ideas related to latent heat.

Question (2) The lower line means that more heat energy is need for each degree rise in temperature. This is because during the water phase, links between molecules (hydrogen bonds) are being broken. Liquid has a fantastic thermal capacity because of this.

Question (3) In steam, the water molecules are far apart in space and heat energy merely increases kinetic energy. In the ice phase, the heat energy is going in to vibrational energy and this varies as the temperature rises.

(2) ***A Hot Mystery***

(a) Form groups of three
(b) Give out a copy of the unit to each pupil
(c) Encourage them to talk to each other and not to try to work individually.
(d) Likely answers:

Part 1 Some kind of idea about specific heat capacities falling with the 'heavier' metals.

Part 2 The same pattern seems to hold true but they need data for more substances.

Part 3 The pattern still seems to hold. to check more quantitatively, they could look at mass of atoms, atomic number, density, size of atoms.

Part 4 Given this data, the pattern may still be true but it is very difficult to be sure.
The key idea is to spot: if the specific heat capacity falls with increases in any of the four characteristics, then multiplying the specific heat capacity by the characteristic might give a constant (like PV is a constant if T is fixed).

Part 5 Given this 'multiplied' data, it is easy to see that density and radius are not really the right factors. Atomic mass looks best but atomic number is also possible.

(3) ***The Puzzle of Electricity***

(a) Form groups of three
(b) Give out a copy of the unit to each pupil
(c) Encourage them to talk to each other and not to try to work individually.
(d) Likely answers:

Page 2 (a) Many possibilities. For example, a bulb between the two wires might light but one between the top wire of *two* batteries would not. Either wire would cause an electroscope to diverge and the use of the second wire would reverse the effect and then cause it to diverge again. If the two wires were dipped into salt water, the smell of chlorine would be found at the wire connected to the copper only.

Page 2 (b) There is no meaning to the words 'positive' and 'negative'. They are merely *descriptions* of opposites. No experiment can show anything about this except that there are *two* effects which are *opposite in some way*.

Page 3 This is really open-ended! They might use two electroscopes and show they discharge each other. They might look for magnetic effects, electrolysis. It is incredibly difficult to show that the negative move easily. The problem is that electrons moving in one direction behaves just like some kind of positive charge moving in the opposite direction! It is possible to look at the speeds of movement of beams of positive and negative charges in vacuum tubes and the relative way of generating the movement which reflects mass/charge ratios.

(4) Water - A Unique Substance

(a) Give out a copy of the unit to each pupil
(b) Part 1 is to be done individually and then form groups of three to compare results.
(c) Encourage them to talk to each other and not to try to work individually.
(d) Answers:

Part 1 (a) E, F
(b) C, K, L
(a) J, M
(a) I
(a) B, E, F, M

Part 2 (a) The cold feeling is related to the rate of heat transfer form the hand to the colder material. Iron conducts heat energy faster but, on touching ice, it can melt, absorbing a huge amount of energy to overcome the latent heat.
(b) Iron has a much lower specific heat capacity compared to water. Therefore, less heat energy is stored in iron.
(c) 1.37×10^{15} Kg
Heat Energy stored = 2.86×10^{15}

Part 3 (d) The original ways depend on measuring the temperature rise at top and bottom of waterfalls but the rise is very very low.
It is also possible to take a cylinder of water containing pieces of rock and rotate the cylinder for a long tim, measuring the temperature of the water before and after, relating the input mechanical energy to the temperature rise. Calculation will show how small the temperature rise will be.

(5) *The Big Challenge*

(a) Form groups of three
(b) Give out a copy of the unit to each pupil
(c) Encourage them to talk to each other and not to try to work individually.
(d) Likely answers:

Part 1 Their first guess may be anything but the second estimate should come nearer to 10^{-24} g
Part 2 They should come up with about 3 or 4 equations.
Part 3 Getting atoms all to move in one direction. It might seem easy to think in terms of rapid flow through a narrow jet. Probably, they will not think of an accelerated beam of charged particles.
Part 4 They might come up with altering the 'negativeness' om the charged plate but it still leaves it uncertain how they can measure velocity.
Part 5 They may well think of deflection in electrical or magnetic fields.
Part 6 They should come up with simple deflection in the diagram
Part 7 If they can think in terms of two particles of different mass, then the extent of deflection will vary.
Part 8 This offers the answers in terms of the *principles* involved in the mass spectrometer.
Problems: two major ones: how do we ensure singly charge particles always? There is no absolute mass, no scale on the detector. So it has to be *relative* mass.

Appendix

F

Digit Span Test

Instructions

This is carried out in the following way:

(1) Give each student a sheet with spaces for writing down answers
Instruct them to write their names, matriculation numbers or some other identifier.

(2) Read them the following instructions:

"This is an unusual test. It will not count for your marks or grades in any way. We are trying to find out more about the way you can study and this test will give us useful information. You will not be identified in any way from it.

I am going to say some numbers. you must not write as I speak. When I stop speaking, you will be asked to write the numbers down the boxes on your sheet.

Are we ready? Let's begin.

(3) You say the numbers ***exactly at a rate of one per second*** (use a stop watch or heart beat to keep your time right. You allow the same number of seconds for the students to write down the answers. Thus, if you gave the numbers: 5,3,8,6,2. You give them five seconds for writing them down. I follow the procedure:

"5,3,8,6,2 - say: 'write' - five seconds allowed for writing, then, say: 'next'"

(4) Here are the numbers used by Elbanna in his early work:

5	8	2						
6	9	4						
6	4	3	9					
7	2	8	6					
4	2	7	3	1				
7	5	8	3	6				
6	1	9	4	7	3			
3	9	2	4	8	7			
5	9	1	7	4	2	8		
4	1	7	9	3	8	6		
5	9	1	9	2	6	4	7	
3	8	2	9	5	1	7	4	
2	7	5	8	6	2	5	8	4
7	1	3	9	4	2	5	6	8

(5) When this is finished,.....allow a short break and then....

You now give a second set of instructions.
"Now I am going to give you another set of numbers. However, there is an added complication!
When I have finished saying the numbers, I want you to write them down in ***reverse*** order.
For example, if I say "7,1,9", you write it down as "9,1,7".
Now, no cheating!! You must not write the numbers down backwards.
You listen carefully, turn the numbers round in your head and then write them down normally.
Have you got this? Let's begin."

(6) Here are the numbers:

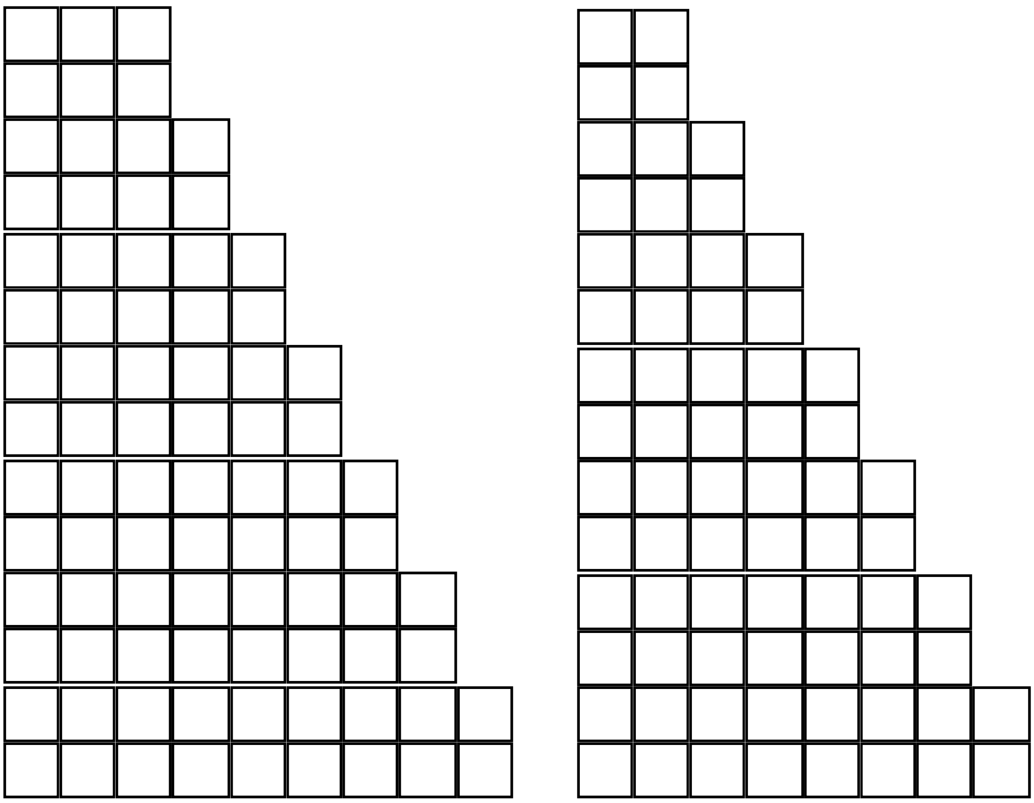
2	4						
5	8						
6	2	9					
4	1	5					
3	2	7	9				
4	9	6	8				
1	5	2	8	6			
6	1	8	4	3			
5	3	9	4	1	8		
7	2	4	8	5	6		
8	1	2	9	3	6	5	
4	7	3	9	1	2	8	
9	4	3	7	6	2	5	8
7	2	8	1	9	6	5	3

(7) This is the version used for adults (those over 16).

(8) Marking: the main thing is to be consistent. Ideally, if a person achieves success at, say, 4,5,6 and 7 but fails at eight digits, then their working memory is 7. However, they can often fail an odd one (by simple slips) or suceed at one at, say, eight digits and fail at the other. I use the simple rule that, for a single failure followed by two correct answers, I ignore the failure. For those who fail at one and success at the other at one leve, just be consistent: I would give them that level.

Note also: check the number sequences above to check if any sequence of nuimbers has any pattern in your cultural setting (like a radio wavelength, a car registration code or whatever...)

(9) The student answer sheet will look something like:



Forward Test Backward Test

UNIVERSITY
of
GLASGOW

Digit Span Test

This test is part of a study which aims to find Working memory space related to scientific thinking and learning physicse
Your response will be treated in complete confidence.

Do not write your name

How Many Can You Remember

Your Name ……………………………………………………………………

Name of school ……………………………………………………………………

Grade ………………… Class …………………

Write the numbers in the boxes below:
Do not write anything until told to do so

Numbers Test Forwards

	NUMBERS								
4									
5									
6									
7									
8									
9									

Numbers Test Backwards

	NUMBERS								
4									
5									
6									
7									
8									
9									

Thank you for your cooperation

Appendix G

The Chi-square Test ($\chi 2$)

The chi-square test is said to to be one of the most widely used tests for statistical data generated by non-parametric analysis. There are two different of applications of chi-square test. These are used in this study.

(1) Goodness of Fit Test

This tests how well the experimental (sampling) distribution fits the control (hypothesised) distribution. An example of this could be a comparison between a group of experimentally observed responses to a group of control responses. For example,

	Positive	**Neutral**	**Negative**	
Experimental	55	95	23	N(experimental) = 173
Control	34	100	43	N(control) = 177
				(using raw numbers)

A calculation of observed and expected frequencies lead to

	Positive	**Neutral**	**Negative**
fo = observed frequency	*55*	95	23
fe = expected frequency	33	97	42

Where *fe* = [N(experimental)/N(control)] X (control data) or (173/177) X (control data)

The degree of freedom (df) for this comparison is 2. This comparison is significant at two degrees of freedom at greater than 1%. (χ**2** critical at 1% level = 9.21)

(2) Contingency Test

This chi-square test is commonly used in analysing data where two groups or variables are compared. Each of the variable may have two or more categories which are independent from each other. The data for this comparison is generated from the frequencies in the categories. In this study, the chi-square as a contingency test was used, for example, to compare two or more independent samples like, year groups, gender, or ages. The data is generated from one population group. For example,

	Positive	Neutral	Negative
Male (experimental)	55	95	23
Female (experimental)	34	100	43

(Actual data above)

	Positive	Neutral	Negative	N
Male (experimental)	55 (44)	95 (96)	23 (33)	**173**
Female (experimental)	34 (45)	100 (97)	43 (33)	**177**
Totals	**89**	**195**	**66**	**350**

(Expected frequencies above in red)

The expected frequencies are shown in red in brackets ( ), and are calculated as follows:

e.g. 44 = (173/350) x 89

$$\chi 2 \quad = 2.75 + 0.01 + 3.03 + 2.69 + 0.09 + 3.03$$
$$= \mathbf{11.60}$$

At two degrees of freedom, this is significant at 1%. (**χ2** critical at 1% level = 9.21)
The degree of freedom (df) must be stated for any calculated chi-square value. The value of the degree of freedom for any analysis is obtained from the following calculations:

df = (r-1) x (c-1)

*where **r** is the number of rows and **c** is the number of columns in the contingency table.*

Limitations on the Use of χ2

It is known that when values within a category are small, there is a chance that the calculation of χ2 may occasionally produce inflated results which may lead to wrong interpretations. It is safe to impose a 10 or 5% limit on all categories. When the category falls below either of these, then categories are grouped and the df falls accordingly.

Correlation

It frequently happens that two measurements relate to each other: a high value in one is associated with a high value in the other. The extent to which any two measurements are related in this way is shown by calculating the correlation coefficient. There are three ways of calculating a correlation coefficient, depending on the type of measurement:

(a) With integer data (like examination marks), Pearson correlation is used. This assumes an approximately normal distribution.
(b) With ordered data (like examination grades), Spearman correlation is used. This does not assume a normal distribution.
(c) With ordered data where there are only a small number of categories, Kendall's Tau-b correlation used. This does not assume a normal distribution.

Sometimes, the two variables to be related use different types of measurement. In this case, none of the methods is perfect and it is better to use more than one and compare outcomes. It is possible to use a Pearson correlation when one variable is integer and other is dichotomous. The coefficient is now called a point biserial coefficient.