University of Glasgow
Centre for Science Education

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of
GLASGOW

Understanding and Accessibility in Physics

By

Mojgan Matloob Haghanikar

B.Sc.

Shahid Beheshti University of Iran

A Thesis submitted in fulfilment of the requirements for the degree of Master of Science (Science Education), Educational Studies, Faculty of Science, University of Glasgow.

October 2003

Abstract

This study is about making physics accessible to learners. The strategy adopted was to promote active participation of students and to investigate students' understanding of the basic concepts. The previous findings from educational research and learning models have been discussed and a wealth of pieces of research have been studied in attempt to determine why learners find physics difficult.

Part of the research was focused at university level and involved courses in Positional Astronomy and Special Relativity. Having explored the areas of difficulty in these two courses by the means of a difficulty survey and questionnaires, two pilot units were devised. These consisted of a series of self-diagnostic tasks intended to probe students' fundamental understanding of the most basic concepts. The aim was to help students step-by-step to modify their own understanding. The method employed here is in accord with constructivist view of learning and close to Ausubel's ideas of meaningful learning.

The contributions of this study was to reveal the lack of conceptual understanding in these fields and to examine an application of an alternative style of teaching. This study was a small prototype for a much more extensive project. The long-term target is to develop on-line, self-diagnostic learning material to help students to correct their basic conceptual understanding. The results suggest that this target is attainable.

A second study was carried out in schools. Here a different approach toward active participation of the learner was adopted which was collaborative working. For this purpose, a unit was developed for a collaborative working on the base of Britain's primary energy resources. The style of the unit was based on role play technique. In this technique, students had to interact with problematic issues which may face the society and where they had to apply their science knowledge in order to reach balanced acceptable solutions.

The school study revealed that there are severe difficulties in grasping the concept of energy. Most of the students reported there is too much information to absorb. In this experiment group working was helpful for students to learn more in-depth. Moreover, the role play technique was helpful to shed light on social aspects of the science and link the science classes to their applications in daily life.

Acknowledgements

The investigation described in this thesis has been part of an ongoing programme carried out in the Centre for Science Education, Faculty of Education, University of Glasgow.

I would like to extend my heartfelt thanks to my supervisors Dr. Norman Reid and Professor Rex Whitehead for their intellectual contributions and their ongoing support in all the stages of preparing this piece of work.

I am extremely grateful to the Department of Physics and Astronomy for their invaluable assistance, in particular Professor John Brown due to his help in initial stages of the project. Specially I am indebted to Dr. Declan Diver, Dr. Martin Hendry and Dr. Lyndsay Fletcher who freely gave their time and talents to help me and the opportunity they provided for me to visit the classes and for the comments and insights they brought in to the results.

Thanks are also due to the students of Department of Physics and Astronomy for their volunteer attendance in the survey and also to the students and teachers of the Longbenton Community School for their participation in the school experiments.

These achievements would not have been possible without the financial support of the British Council through the Chevening scholarship award, also thanks to my International advisor Mrs. Avril MacGregor for her support in the final stages of the research.

Special thanks to my best Scottish friends Finlay and Christine Mackenzie for their warm and welcoming mood in attempt to promote international friendship. Their help and friendship was always encouraging during this period.

Most of all, my work would not have been completed without the help and patience of my mother and my sister.

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Chapter 1

Introduction

1.1 Making Physics Accessible

The subject of this thesis is 'making physics accessible'. The use of the word 'accessible' requires explanation. In one sense, physics is accessible to anyone who goes to school, to anyone who can read a book, or nowadays, to anyone who can log on to the World Wide Web. That is not the sense in which the word is used here. Instead we are interested in providing 'access' to the understanding of the world that physics explores. *Knowing* Ohm's law is useful in designing or building electrical circuits; *understanding Ohm's* law unlocks many interrelated ideas concerning electricity, energy, heat, diffusion and so on which can in turn unlock further understanding in areas of the physical world which at first seem to be unconnected with the electrical resistance of a piece of wire. This is the sense in which 'accessibility' is used here.

This project is not aimed at the initial teaching of physics. We assume that that is being done, and that the methods used by the teachers and the underlying pedagogic theories (if any) are fixed and inaccessible to us. What we seek to do is to provide challenges to the students designed to help them decide if they have understood what they have 'learned' and to act as guides to building or reinforcing correct connections with their previous knowledge.

The classic diagnostic of incomplete knowledge or incorrect connection is the paradox. When two lines of reasoning about the same situation lead validly to two different conclusions then something is not correctly understood.

The power of the paradox is illustrated by the motion paradoxes of Zeno (490 BC), the most famous being that of Achilles and the Tortoise. Achilles (a famously fast runner) and a tortoise (a famously slow one) have a race and, out of fairness, Achilles gives the tortoise a start. We know that, however large a start the tortoise is given, Achilles will eventually catch up, pass the tortoise, and win the race. On the other hand one can reason as follows: before Achilles can pass the tortoise, he must get to the point from which the tortoise started and, however fast he is this takes some time. While Achilles is getting to that point the tortoise moves on. Achilles then has to get to the point where the tortoise now is, and in the time he takes to do that the tortoise moves yet further. No matter how many such stages are considered the tortoise is always a little ahead of Achilles. Thus, even after an infinite number of stages Achilles can not catch the tortoise, which is contrary to the argument from common experience. We have, then, two different, but apparently valid, conclusions about the outcome of the race.

This paradox took nearly two thousand years and many developments in mathematical understanding before it could be resolved satisfactorily. The resolution depended on the recognition that there is indeed an infinite number of the steps described before Achilles catches the tortoise, but each step takes less time than the preceding one (or less distance), and that the sum of an infinite number of things (distances or times) could in these circumstances be finite. The possibility of the existence of a finite sum for an infinite series of things is now one of the cornerstones of mathematical analysis. It would be wrong to suggest that Zeno's paradox led at long last to a mathematical breakthrough. Instead, it showed that all was not well with mathematical understanding, and, when the developments of the 18th century uncovered the ideas of limits and of convergent series, it was immediately seen that the resolution of the paradox had been achieved.

One paradox that truly did play an important role in demonstrating a serious flaw in knowledge and led instantly to new and profound investigations was that of the Barber of Seville[1], which can be easily stated but not easily analysed. This, in its abstract form concerning "the set of all sets which are not members of themselves", revealed the existence of totally reasonable but unwarranted assumptions and shook the foundations of mathematical logic.

Knowledge grew through the centuries in such a way that new facts fitted on to existing knowledge or led to new theories. Learning may perhaps follow similar patterns. Piaget (Piaget & Inhelder, 1969) described the processes by which a person constructs his or her own knowledge. When (s)he encounters a new situation, (s)he will attempt to fit the new information into existing mental schemes of thought. Thus, the existing beliefs will either be strengthened or modified as a result of new information. There are arguments about the way in which science develops. Vosniadou and Ionannides (1998) discuss some of these

[1] In Seville there lives a barber who shaves everyone in the city who does not shave himself. Does the barber shave himself? Assume he does; then he is by definition one of those who does not shave himself, and this is a contradiction. Assume he does not; then he is by definition one of those shaved by the barber (i.e. himself) and this is also a contradiction. Thus there is not even an answer to the question which does not lead to a contradiction. There is obviously something wrong with the statement of the problem, but what?

and argue that some of Piaget's ideas are mirrored in the way in which 'normal science' and 'scientific revolution' (as they describe it) have developed. Such ideas relate to those of philosophers of science such as Kuhn (1970) and his attempt to explain theory change in the history of science.

The constructivist view of learning developed from some of Piaget's ideas. This perspective acknowledges that the individuals are a central part in constructing their own meaning in order to make sense of the world. Therefore, making sense of the world is based on the individual's active construction of meaning (Driver and Oldham 1986). Piaget can be regarded as a constructivist as he emphasised the way the learner constructs knowledge and he recognised the importance of the self-regulation process in individual learning (Driver and Oldham 1986). It is even possible that, in the constructivist-oriented way of thinking, students in different cultures will have different views about science (Cobern 1996). Ausubel (1968), in his model of meaningful learning, suggested that new pieces of information must be linked to prior knowledge and existing understandings if the learner is likely to be able make sense of new information.

However, if the constructivist notion is correct, it is possible that the linking of the new and the old may be defective; it may not happen at all, or it may connect the new information with the wrong old knowledge, or there may be nothing at all for the new information to link to. These failures, unlike those revealed by the paradoxes, are individual and student-specific. The main thrust of this thesis is to investigate whether it is possible to reveal those defects in understanding and correct them.

Chapter 2 of this study takes these educational ideas further and is devoted to a discussion of some aspects the psychology of learning in more detail. A short overview of the history of these models of learning has been presented. These led eventually to the powerful predictive models based on information processing ideas.

Johnstone brought together the ideas of Ausubel and the problems of working memory space limitations. In the light of this model, the main underlying reasons for difficulties in learning conceptual subjects like Physics have been discovered. A common factor which seems to appear in all areas of science which students perceived to be difficult is due to the amount of information to be processed at the same time. This exceeds the available working memory space (Johnstone and El-Banna, 1986).

Chapter 3 seeks to present an overview of the underlying reasons for difficulty in learning physics on the basis of research conducted in recent decades. This describes attempts to use educational models in solving the difficulties to expand the knowledge of how students learn. In many topics in Physics, grasping a concept may depend on holding many ideas at once. This makes considerable demands on working memory space which may lead to difficulties.

It is obviously not possible to look at all areas of difficulty in school and university Physics. Chapter 4 describes a way by which the areas of greatest difficulty can be detected and this was applied to a first level Astronomy course. From the outcomes of this survey, two topics were selected: Positional Astronomy and Special Relativity. For these two topics, two units were developed. These were designed to explore whether students really understood the underlying themes and they sought to offer students an insight into their lack of understanding. Both involved a certain amount of cognitive conflict where students had to match experience and their knowledge to seek to find answers to fundamental questions.

These units were for individual use. Chapter 5 describes the use of one unit (on the topic of energy) which was used with 15 year old school pupils. This unit involved group work, which is another way to develop the kind of cognitive conflict as different ideas are shared and become the centre of argument. Some outcomes are described.

This study is a very limited attempt to explore some of the issues on making physics accessible. The aim of this exploratory study is to pin point those areas which look to be useful for further enquiry and development.

Chapter 2

Learning Models

2.1 Introduction

In the developed world even as late as the early twentieth century, the view of teaching was very much along the lines that the learner was a vessel to be filled with knowledge and the role of the teacher was to do the filling. However, the situation is much more complicated and there appears to be no one right way to educate the child. There are physical, social, emotional and verbal communicational needs, in the context of preserving children's curiosity and interest in learning. The main aim of education should not only be to provide an educated young adult but also one who is continuously interested in learning.

In this chapter, the contributions that psychology can make to an understanding of the process of learning will be reviewed. We shall investigate to what extent these theories and principles can be applied to educational practice and particularly in planning for any new educational structure for teaching physics aiming to make it more accessible. Firstly, a few psychological approaches will be summarised to investigate how the development of learning proceeds, how the activity of thinking begins and what provisions are required for meaningful learning. Each model considers different aspect of the learning process. In addition, the effectiveness of these models in our instructional planning will be discussed.

2.2 Jean Piaget's Learning Model

Piaget tried to sketch an integrated theory of child development with its biological basis of adaptation (Piaget, 1961). He never practised as a educator and did not set out to contribute specifically to education and teaching. Nevertheless, his work has had considerable significance for education and teaching. He was a biologist and psychologist who tried to investigate scientifically how a child's thinking develops. As a biologist, he was aware that adaptation is a common feature of all species. According to McNally

(1974), every organism has the ability to interact with its environment in a specific behaviour pattern which is the result of heredity. However, human infants inherit certain skills that can be modified through experience. Piaget believed that each human being inherits the special style of intellectual functioning which interacts with environment in order to develop the intellectual structure. Moreover, the fundamental process (function) underlying the progressive development of human beings is identical and remains the same throughout life. Piaget pointed out that intelligence development is a dynamic process: it is a consequence of adaptation to the environment; he added a second postulate that this adaptation has a basic tendency toward organisation of thought (McNally, 1974).

In contrast with previous psychologists, he regarded the child as an active participant of the process of intellectual development. Prior to Piaget, psychologists believed that the child's brain is similar to that of the adult in the way it functions. In terms of cognitive development, the child gained more knowledge alongside biological maturation and environmental learning. However, Piaget stressed the interactions of the child with the environment in this process. He asserted that brain function develops and evolves by the means of these interactions (Atkinson *et al.*,1993).

As a result of observing numerous Parisian children, he proposed the idea of *schemata*. He noticed that infants inherit natural reflexes and skills which allow them to react to events and objects around them. He called these sensori-motor skills. In this way, an infant can interact with the world and construct exploratory theories regarding the result of his or her experiments. Schema refer to the child's exploratory skills (Atkinson *et al.*,1993). Piaget described the thought processes that bring about adaptation as schemata (Hyde, 1970). After gaining more knowledge, the child will construct a set of schemata and, when (s)he encounters a new situation, will attempt to fit the new information into existing schemes. If the schema does not fit the new situation, the child will alter the existing schema in response to the new stimuli. Piaget called the first process *assimilation* and used the word *accommodation* to describe the process of schema alteration (Piaget & Inhelder, 1969). Assimilation is the realisation that an event fits an existing conception, so it strengthens existing beliefs (Glasersfeld 1987). Accommodation is a result of cognitive disequilibrium, when expectations are not met and events do not fit: there is a tendency for existing beliefs to be weakened.

In fact, assimilation and accommodation are two functions of adaptation operating in two directions. Assimilation refers to the absorbing new knowledge in such a way that it makes sense within existing cognitive structure. In this way, the child attempts to understand new knowledge in terms of his/her existing knowledge. For instance, babies usually grasp and suck the objects in the same manner. Accommodation happens when a child tries to change his or her internal structure to understand new situation. This is when the child learns to treat objects differently. So the child has adapted his or her way of thinking to a new situation. Assimilation, therefore, emphasises the direction from the particular situation to the general structure while accommodation stresses the direction from the general structure to the particular situation (Furth 1970). For example, it is common to think that motion implies the existence a force. However, when the learner realises that motion may involve velocity and/or acceleration, there is confusion in understanding the role of force in relation to motion. To sort this out requires a measure of accommodation (Dykstra 1991).

Piaget observed that some of the characteristics of mental functioning remain invariant. He saw adaptation as one of the invariants of this mental functioning and that it worked in the two direction of assimilation and accommodation (Flavell, 1963). If accommodation and assimilation are in balance, equilibrium will be achieved. Equilibrium is the basic concept of Piaget's model. Intellectual development that starts at birth and reaches fruition in adulthood consists essentially of activity directed towards equilibrium (Mc Nally 1974).

2.3 Piaget's Stages of Intellectual Development

A major contribution of Piaget was the way he observed and described the learner's cognitive development with age. He observed that the child's structure develops and grows up through a series of distinct stages. He categorised the cognitive development into four major stages (Piaget 1961). Much later, Atkinson *et al.* (1993) listed these cognitive stages (table 2.1) and showed that the age boundaries are not completely fixed but are related to cultural background and socioeconomic factors. However, the order of development remains the same for all children.

Table 2.1 Piaget's Cognitive Stages

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 (2-7 years)	Learns to sue language and to represent objects by images and words. Thinking is still egocentric with difficulty in seeing the viewpoint of others. Classifies objects by a single feature eg colour.
Concrete operational (7-11 years)	Can think logically about objects and events. Achieves conservation of number (age 6), mass (age 7) and weight (age 9). Can classify objects according to several features and can order them in series along a single dimension.
Formal operational (11 years on)	Can think logically about abstract propositions. Can test hypotheses systematically. Becomes concerned with the hypothetical, the future, and ideological problems.

Ideas related to the formal learning of physics do not really become important until the latter two stages, but it must be noted that many of the most fundamental ideas in physics are closely related to permanence and continuity. These two stages start with the beginnings of thinking logically and finding relationships. In the concrete operational stage, the operational thinking is starting and logical systems begin to be used. However, this logical thought is related to that which can be seen and touched and appreciated by the senses. It lacks the ability to deal with the abstract and cannot conceptualise hypotheses and causality beyond that which is accessible directly to the senses. Nonetheless, at this stage of education in many countries, abstract ideas of physics start to appear in the curriculum, ideas related to forces, energy and electricity. Teaching scientific ideas at this age should be set, in some fashion, in the context of examples, drawings or that which is directly accessible to the sense in order to get round the limitations observed by Piaget. This is in line with modern educational thinking and in accordance with Bruner's beliefs about linking psychological theories to education (Hyde 1970). Bruner (1966) suggested that 'There is a way of communicating ideas to children that is appropriate to the particular age and it is futile educationally simply to wait passively for the children to grow in readiness'. In this, Bruner is taking a very different approach from Piaget.

Following somewhat unsuccessful attempts to argue that it is essential to wait until the child is ready cognitively, Shayer and Adey (2002) illustrate their most recent thinking and proposed the idea of cognitive acceleration. They tried to find a way to help students to go through the stages faster, instead of altering the syllabus to be in accordance with the cognitive stages. They seem to offer evidence that some acceleration (in Piagetian terms) is achievable by using their excellent set of teaching materials but it was found not to benefit all and is limited in the extent of potential acceleration. In this way, they reflect ideas from Vygotsky (1978) who, in contrast with Piaget, emphasised both individual and social perspectives of learning. In simple terms, Vygotsky found that it was possible to move a learner forward cognitively by a small amount and, perhaps, this is what Shayer and Adey (2002) observed. It is also possible to interpret their observations in terms of information processing (Johnstone, 1996) perhaps the teaching materials are offering some potential chunking strategies which suit some learners (Johnstone, 1980).

During the years from about age 11 onwards, there is the steady development of the individual's ability to understand systematically, to analyse a situation and to test hypotheses. The ability to start to handle abstract notions is developing. In a sense, an hypothesis is the the classic abstract idea in that the pupil is starting to ask, "what if....." types of questions.

Herron (1975) looked at cognitive stages of first year undergraduates. He found not all students were at Piaget's top stage. He concluded that a person might not think formally unless he/she needed to. In simple terms, it is not enough to achieve a certain age for functioning at this stage. It is possible that students who are not operating completely at formal level are behaving this way because they were never required to operate at this level. Herron found a high correlation between students' performance in examinations and Piagetian intellectual stages. He concluded that achieving Piaget's formal operational stage is the prerequisite of comprehending chemistry.

2.3.1 Comments on Piaget's Intellectual Development

Piaget's ideas are now broadly accepted in general terms. Firstly, he demonstrated that, in cognitive terms, children are not miniature adults. There are specific ways in which their learning is different. Secondly, he offered a description of the stages through which children proceed as they move towards cognitive maturity.

Piaget's work is a coherent set of observations but is not a theory. His description does not explain why people go through these stages. It does not refer to the development of memory with age or other factors. Piaget's work has been criticised for its definition of a set of well-defined age related boundaries with sudden transitions from one stage to the next (Ausubel *et al.* 1978). Later work has shown that people do not jump from stage to stage in neat ways. Indeed, a person can be operating at one stage in one context and at another stage in a different context (Novak, 1978; Jenkins, 1978; Dawson, 1978).

Others have criticised Piaget's research methodology, with its low sample sizes, making his work statistically unreliable. Moreover, he used a cross-sectional approach that did not take into account other variables including culture, intelligence and gender. Space does not allow this issue to be expanded further here. There is a clear message in terms of making Physics accessible. The typical introduction of abstract Physics concepts before an appropriate stage of cognitive development will almost guarantee problems. This may lead to a tendency to depend on rote recall rather than understanding or it may contribute to the huge number of misconceptions which have been identified in many research studies (e.g. Osborne *et al.* 1983, Driver 1989 and Baxter 1989a, 1989b). It should be noted though that most of the students with which this work is concerned have, or should have, passed through all of the Piaget's stages.

2.4 Gagné's Learning Model

While Piaget emphasised that learning depends on cognitive development, Gagné is one of many educational psychologists who looked at learning in the context of a systematically organised activity where the teacher had a major role to play.

Gagné is well known for his work on the "Conditions of Learning" (Gagné, 1977,1985). In his model, he outlined what he considered to be the building blocks of the learning process. This theory contains a taxonomy of learning outcomes and stipulates the learning conditions for the achievement of each outcome.

There are three basic components in Gagné's theory: A taxonomy or classification of learning outcomes; *internal and external factors* necessary to achieve the learning outcomes; and nine levels of instruction which are used as a guide to design a curriculum or to teach a subject. Gagné argues that there are different levels of learning and that these types of learning have different internal and external conditions that support them (Gagné 1977).

2.4.1 Gagné's Taxomony

According to his taxonomy of learning outcomes, each human has different learning capabilities. He defined learning which will occur when one of these capabilities changes. He believed learning depends partly on the process of growth but also depends on the individuals life style (Gagné, 1977). The outcomes will provide the learners with the improved skills, which can able them to learn. The five major categories of learning are (Gagné and Briggs 1974).

Intellectual skills	enabling a human to understand his environment;
Cognitive strategies	referring to the strategy a person adopts to learn;.
Verbal information	the knowledge we store about all matters around us (essentially factual information);
Motor skills	the physical skills that are necessary to be learnt in life (like bicycle riding and computer skills);
Attitudes	the kind of knowledge concerning individual reaction toward external items.

2.4.2 Gagné's Instructional Levels

Instruction is one of the external conditions that should be different for different types of learning outcome. For example, learning attitudes is different in nature from learning intellectual skills or motor skills. In this way, it is very important for teachers or curriculum developers to be aware of the nature of task and use the correct relevant structure (Gagné 1970). This kind of thought can bring a great responsibility for human society. Nonetheless, Gagné suggests that, although different in detail, the same instructional pattern is needed for all learning outcomes. He stipulated that there are nine general instructional level (Gagné *et al.* 1992).

* *Gaining Attention*
* *Informing the learner of the objective*
* *Stimulating recall of prior learning*
* *Presenting the stimulus*
* *Providing learner guidance*
* *Eliciting performance*
* *Providing feedback*

* *Assessing performance*
* *Enhancing retention and transfer*

2.4.3 Prerequisite in the Learning of Intellectual Skills

Among the five categories of learning outcomes, Gagné emphasised intellectual skills. According to Gagné *et al.* (1974), "Intellectual skills are of central importance to the school programme and provide the best structural model for instructional design". It is important to understand that the categories of intellectual skills are regarded as hierarchical. According to Gagné's theory, the way to determine the prerequisites for a given learning objective is to construct a learning hierarchy. Most learning outcomes are complex, each outcome must be subdivided into a hierarchy of pre-requirements, on the basis of which learning outcome has been considered. Here is his abbreviated version of intellectual skills sub-categories (Gagné *et al.*,1974).

Discrimination:	A recognition that classes of things differ
Concrete concept:	An ability to classify things by their physical features alone
Defined concept:	An ability to classify things by their abstract features (perhaps also including physical features)
Rule:	The ability to apply a simple procedure to solve a problem or to accomplish some task
Higher-order rule:	In this, there is the ability to use complex procedures in order to solve a problem or accomplish some task

Gagné (1968) believed that subjects should more or less follow this list of events in sequence for learning to be meaningful to the learner.

2.4.4 Comments on Gagné's Model

Gagné has been criticised from different point of views. Soulsby (1975) asserted that his model lacks the affective domain of the learner. It does not tell about the external conditions and, according to Mahmoud (1979), the hierarchy overloads the working memory space.

In a major study of the logical steps which pupils were taught to use in handling formulae and equations in chemistry, Howe and Johnstone (1971) found that pupil success was more often dependent on memory skills rather than on the use of this kind of logical reasoning. They were following the ideas proposed by Gagné but their attempt to develop the logical reasoning steps with pupils was found not to be the most helpful way forward. This study suggested that, although Gagné's ideas seem to be a sensible way to approach the development of instructional strategies, there is considerable doubt if learners are as logical as the theory suggests. Perhaps learners use all kinds of strategies and the dependence on memory is much more important than the use of logical sequenced procedures. This has important messages for any attempt to make Physics accessible through the use of teaching materials.

2.5 Ausubel's Learning Model

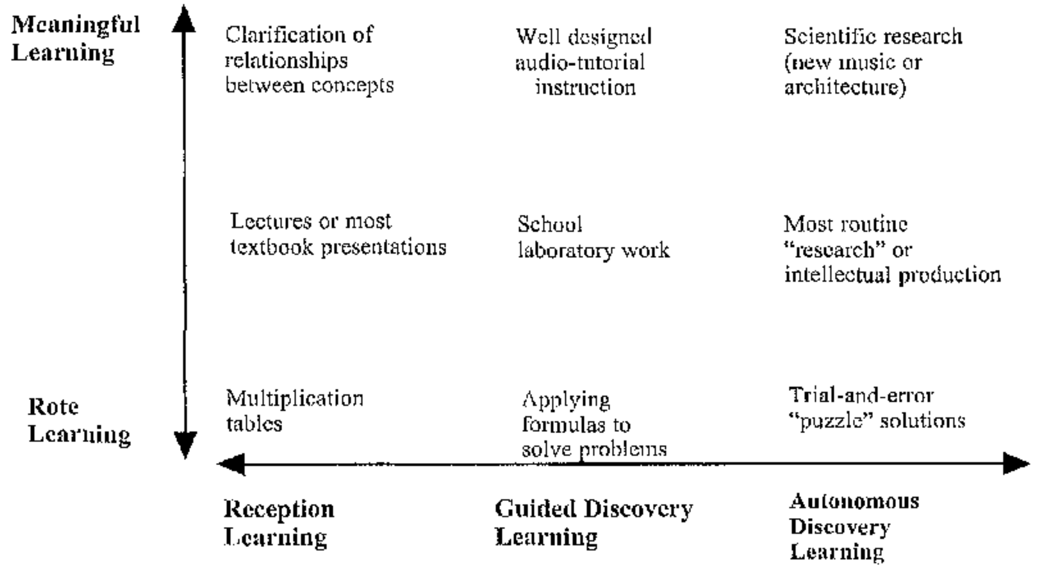
David Ausubel's contributions to the psychology of learning have been well recognised among both educational psychologists and educators alike. He maintained that learning is initially related to what the learner already knows (Ausubel *et al.* 1978). Piaget's stages are then to be seen as consequences of the amount of knowledge the learner has, rather than as discrete phase of development. In contrast with Bruner's discovery learning (Bruner, 1966), Ausubel (1968) described an alternative method of instruction called *reception learning* . This model suggests that it is the job of the teacher to structure learning, to select appropriate materials for the students, and to present them in a well-organised fashion. Ausubel also maintained that students may need external motivation (such as quizzes and exams) to enhance learning.

Ausubel investigated the role of educational psychology in teacher education and meaningful class learning. However, the established psychological principles of learning in his day were not really designed for the actual classroom. He thought educational psychology should have basic rules to help education in practice that is usually in the form of classroom teaching (Ausubel *et al.* 1978). Without a systematic set of psychological principles applicable in the classroom, the teacher must rely on traditional methods or discovering effective learning methods through trial and error. Ausubel is arguing for the need for a systematic understanding of how learning takes place so that teachers can plan on a sound basis.

2.5.1 Types of Learning

Ausubel distinguished two dimensions for classroom learning: the *rote-meaningful* and *reception-discovery* dimensions. Rote learning can be distinguished from meaningful learning and reception learning can be compared with discovery learning. but the two dimensions are different. Ausubel argued that each dimension is a continuum. Ausubel *et al.* (1978) presented a diagram comparing the two continuum dimensions of learning (figure 2.2) and this has proved to be a useful way to clarify ideas.

Figure 2.1 Two Dimensions of Learning (from Ausubel *et al*, 1978)



Most classroom learning is seeking to be based on meaningful reception learning and more often the learner learns through reception rather the discovery. In reception learning, the content is presented to the learner. What the learner needs to do is to relate the new learning material to his/her existing structure of knowledge. Moreover, the materials are often presented verbally and, thus, Ausubel concentrated on verbal reception meaningful learning.

Reception learning can be either rote or meaningful. In the case of meaningful reception learning, the meaningful process of internalisation should take place where the new knowledge is correctly related to previous held knowledge. In the case of discovery learning, the concept to be learnt must be discovered by the learner, before being assimilated to the learner's cognitive structure. The process of discovery learning is quite different from reception learning. According to Ausubel *et al.* (1978), "the learner must rearrange information, integrate it with existing cognitive structure, and reorganise or transform the integrated combination in such a way as to generate a desired end-product or discover a missing means and relationships."

Ausubel believed that discovery and reception learning have different roles in intellectual development. However, reception and discovery learning sometimes coexist in learning processes. For example, everyday problem solving can involve discovery learning or it can be used in the classroom to clarify, find relationships, evaluate, integrate. Laboratory work can include range of forms of learning including discovery learning.

2.5.2 Conditions of Meaningful Learning

The process of meaningful discovery learning is much more complicated than meaningful reception learning. Thus, Ausubel focussed on reception verbal meaningful learning. In meaningful reception learning, the new material is relatable to the individual's cognitive structure. If the learner memorises the new knowledge and adds it to his/her cognitive structure, without interacting with what already exists, the learning is rote. It is meaningless in the sense that it does not relate in any meaningful way to other knowledge. That does not necessarily imply that it is not useful: for example, learning the alphabet may be rote but it not a useless activity; memorising a formula in Physics may be rote but it may be a valuable tool in bringing ideas together as well as gaining correct answers.

Secondly, Ausubel stated that the nature of learning material also should be relatable to the learner's cognitive structure. This may also necessitate the availability of such relevant ideas in the individual's cognitive structure. With this view, Ausubel emphasised that prior educational background, age, IQ, occupation, social class and cultural membership are all fundamental determinants for meaningfulness of learning.

Unlike Piaget, Ausubel did not define age development stages, but he believed the amount of a learner's knowledge is related to his/her age. Essentially, Ausubel stated that what the learner knows determines what he/she will learn.

> *"If I had to reduce all of educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly."* (Ausubel, 1968)

His advance organiser approach to teaching is one of the most utilised methods of instruction. The term advance organiser, as used by Ausubel, stands for a statement (or many statements) which is given before instruction of new material that relates it to existing knowledge. It acts as a "subsuming bridge" (Ausubel, 1963) between new learning material and existing related ideas.

Ausubel (1962) believed that the learning material itself is one of the determinants of meaningful learning. The learning material can support logical meaningful learning if it is designed in a well organised structure, free from randomness and arbitrariness. The learning material should be non-arbitrarily relatable to relevant ideas. For example, if a symbol carries two meanings, it is important for the learner to know which is being used. The learning materials which have relation to experiences or strong memories that are more likely to be retained: "Rotely learned materials are discrete and isolated entities which have not been related to established concepts" (Ausubel, *et al.* 1978).

It is possible to interpret Ausubel's ideas so as to offer teachers a way to improve their students' learning.

* *What students already know should be ascertained;*
* *Learning materials should be well organised;*
* *New ideas and concepts must be potentially meaningful to the learner;*
* *Anchoring new concepts into the learner's already existing cognitive structure will make the new learning knowledge meaningful;*
* *The broad outline of a subject should be presented first and then progressively differentiated in terms of detail and specifics;*
* *Instructional materials should attempt to integrate new material with previously presented information through comparisons and cross-referencing of new and old ideas.*

Ausubel's contribution to the understanding of learning has been considerable. Firstly, his distinction between the two dimensions of *rote-meaningful*[1] and *reception-discovery* has offered an important clarification of ideas. In Physics education, the emphasis must be on meaningful learning and, yet, if the learner cannot make sense of what is offered, there may be a tendency to fall back on rote learning, making the very nature of Physics meaningless and highly unattractive.

However, his major insight into the importance of what is already known and how it was

[1] One must be careful in interpreting the rote-meaningful dimensions. There is a natural tendency to regard *rote* as bad and *meaningful* as good. That this is not necessarily correct can be seen by considering the education of musicians where rote learning (learning to play the right notes, learning scales and chords etc and continual practice) is regarded as good, and even virtuous. What *meaningful* means in this context is open to debate, but it is certainly not what is meant when one speaks of meaningful learning in chemistry or physics.

learned if new learning is to be meaningful is vitally important in a subject like Physics. When learners are exposed to abstract topics in physics, if they have no previous organised knowledge or appropriate ideas to make the links, meaningful learning is unlikely to occur. The first step is to make the *language* accessible to the learner. Then it is important to give meaning to ideas using familiar examples from daily life. For instance, in the topic of energy, a very large number of energy transformations can be exemplified using familiar circumstances. They argued that it is not appropriate to define energy in term of work at the outset, because work depends on the abstract concept of force[2].

Finegold and Gorsky (1991) pointed out that students commonly adhere to scientifically incorrect beliefs about force. In a students' framework, motion often implies force and in the direction of motion. These students would have a great difficulty in applying Newton's laws. Prior non-scientific frameworks that emerge from sensory experiences should be eliminated and make the students ready for conceptual change. Instructors should be aware of many ways that students can misinterpret.The ideas and expectations that students bring in to class is a matter of concern that may lead to misconceptions. Even students may mislead in the situations that they have no background. Many scientific terms in physics such as energy, acceleration, force, work are terms commonly used in daily life. For example, according to Harrington (1999), students usually hold the idea that only conductors can be charged. This interpretation is consistent with the idea that insulators protect you, thus cannot be charged.

The most controversial and noteworthy method which Ausubel has introduced is the idea of the "advance organisers". These are not merely previews of the subject material that is to be presented. Advance organisers are more general, abstract concepts that will provide the great context to which the new information can be subsumed and anchored (Ausubel, 1963). The advance organisers can be designed in the form of reading materials, prelectures or prelabs or any other presentation which provides bridges between what learner already knows and what is to be learned. They also prepare the mind of the learner by organising their background knowledge and relating new information to their previous knowledge. For example, Sirhan *et al.* (1999) provided powerful evidence for this in a university chemistry course by showing the effectiveness of prelectures. Sirhan and Reid (2001) continued this work, showing that the prelecture idea could be modified into written materials (chemorganisers - Sirhan and Reid, 2002), given a design that imitated

2 The difficulty apparent here is "what is abstract?" There is nothing obviously more abstract about "force" than about "energy". Perhaps it is *familiarity* which should be spoken of.

the features of prelectures. The power of this approach in enhancing learning was quite marked, with the less well qualified students gaining most. In other research, Johnstone *et al.* (1998) examined the effectiveness of pre-laboratories with undergraduates. They found that preparation before laboratory sessions improved physics practical work in a number of ways. Firstly, there was a marked improvement in learning and this could be demonstrated as enhanced student performance in the ways students applied the ideas arising from the experimental work in new situations. Secondly, they found very large positive attitudinal gains with the students.

The usefulness of advance organisers may differ strongly from student to student. Because most good learners already have the ability to organise new information, the organisers may have little additional effect. But for slow learners, Ausubel (1968) believed that organisers are extremely helpful as this group of students needs additional help structuring their thinking. This is consistent with what Sirhan and Reid found (Sirhan and Reid, 2002). The importance of this cannot be overestimated in that it offers the teacher of Physics a way by which the performance of the *less well qualified* can be enhanced preferentially.

2.6 Neo-Piagetian Models

Many researchers attempted to *explain* what Piaget had observed, trying to interpret his work in terms of their own understanding of the way that human mind handled information. One of the first was Pascual-Leone (1974), who considered that human performance on cognitive tasks was dependent on three *factors*:

1. The demand of the task on the individual's mental capacity;
2. The mental strategy that is required to perform the task successfully;
3. The individual's available mental capacity.

He thought that Piaget's stages of intellectual development were related to *working memory capacity* [although he did not use this particular phrase]. He appreciated that mental capacity grew with age and also that the range of strategies available to the student would grow with experience and with education.

Case (1974) developed very similar ideas He suggested that the Piagetian idea of *schemata* were parallel to the *factors* described by Pascual-Leone, which were thought of as the skills the students might bring to solve the problem. This can be seen as kinds of mental blueprints or procedures that students could bring to a learning situation or a problem solving situation. He believed that this repertoire of schemata developed with age and experience.

With their ideas, they were distinguishing between the mental capacity of the students and the repertoire of the schemata. However, the working memory space not only handled information, but also had to be available for applying an appropriate schemata (Case, 1974)

Case did not consider that mental capacity could be increased by means of instruction (Case, 1974). In this, he was definitely following the observations of Piaget himself in seeing cognitive development as strictly chronological. However, Case argued strongly that increasingly complicated strategies could be seen as offering the learner a more sophisticated repertoire of schemata. While this neo-Piagetian perspective was heavily criticised by Trabasso and Foellinger (1978), their perspective on learning and problem solving led to important developments in information processing.

Much later Niaz (1987), showed that a relationship existed between the mental capacity of students and the information demands of the questions, in terms of students performance. This type of relationship will be explored in more detail in the next section.

2.7 Information Processing Models

The idea that the brain operates somewhat like a computer can be traced back at least to Craik (1943) and von Neuman (1958). In Craik's time the only computer which could be said to process information, as opposed to simply doing numerical calculations, was Kelvin's tidal predictor. The architecture of the modern computer was developed shortly after Craik wrote. There were input and output devices, various classes of storage, or memory, suitable for rapid access or for bulk storage, and processing units which could operate on the contents of the stores. These von Neuman architecture machines had the ability to be programmed by reading instructions into their memory. Typically the memory space is shared between instructions and the data they operate upon, and what the computer is doing at any instant is determined not by its construction (hardware) but by what is in the relevant part of its memory (software).

The broad similarities between input and output and the human (or animal) sensori-motor systems, between storage and memory, and between programming and learning, provided psychologists and others with a new language and a framework within which to discuss the problem of human learning. Theories constructed within this framework are called *information processing* models. Their great importance in comparison with earlier descriptions is that they can be made *quantitative* and used to be make predictions which can be tested experimentally.

2.7.1 Memory

Different kinds of memories hold different kinds of information. Memory consists of subdivisions which can internally interact and each part is able to register, store and retrieve. These ideas have been the basis of experimentation during recent decades. Atkinson and Schiffrin (1968) presented a model for the structure of these sub-components which is named the *modal* model. In this model, the human's memory is divided in to three sections. Stimuli pass through sensory channels or *registers* (visual, auditory, touch, taste and smell) to reach the *short-term memory or working memory.* This part of memory is capable of processing the input information and relating it to *long-term memory.*

2.7.2 Sensory Registers

The sensory memory holds all the information which is received from our five senses[3]. The capacity of this memory is large but, information lingers in this memory for just a few seconds.

Baddeley (1999) described that there are probably more than two memory systems and sensory memory itself is fed by series of sensory registers working together. Sensory registers concerns five senses. For example, sensory memories can occur in terms of vision and hearing. Auditory and visual information is persistent and this is the reason that we can perceive a movie continuously or track a sound. Baddeley (1999) has carried out a set

[3] The *five senses* usually are taken to mean those that we are concious of. There is nothing though to say that the sensory memory does not at any time also hold information derived from unconscious senses, for example the autonomic nervous system.

of experiments which show that auditory information is more durable than visual information.

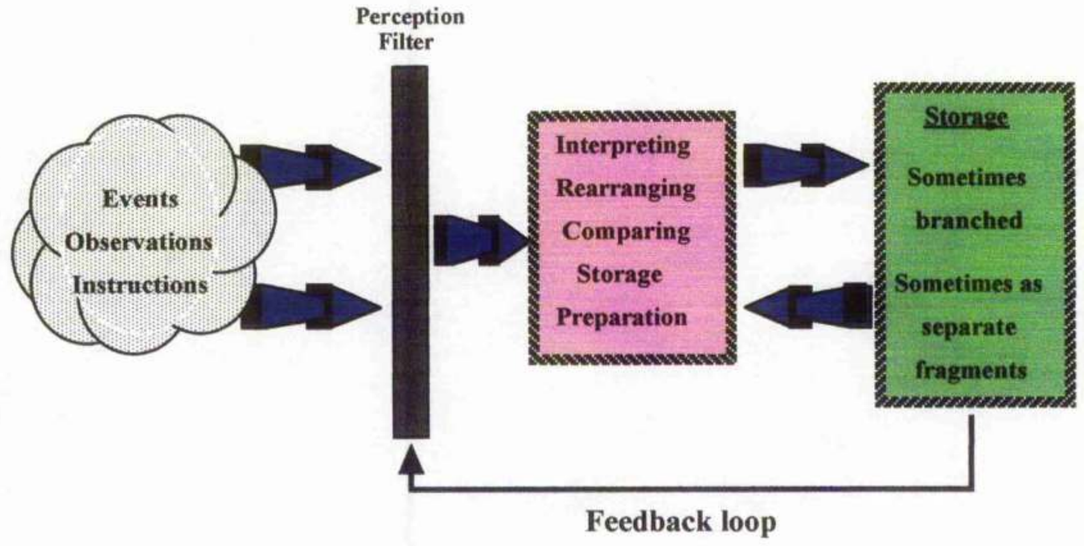
Through reception channels, a large amount of information is received but most of this information is ignored. The amount of information that bombards our senses is huge and it is impossible to respond to all of it. The question is how the sensory register selects among millions of bits of data or, more precisely, how this process of selection can affect classroom learning. In fact, the learner selects that particular part of the incoming stimuli which is most important. The decisions about what is most important will be, potentially, unique to each learner.

After the selecting stage, the collected information has to be encoded. This means that the information which has been received has to be be transformed somehow to be acceptable for storage by long term memory.

Perception is used to describe a meaning that the mind will construct from the bits of selected sensory information. For example, the imagination of three dimensions from two dimensions, or completing an incomplete pictures, grouping and making stereotypes and finding relations between similar things. Overall, the human perceives the whole rather than sensory features.

In general terms, Johnstone (1991) described the sensory registry as a perception filter. In figure 2.3 he has proposed a model to show how the perception filter is affected by previous knowledge. This model strongly confirms Ausubel's model and unifies various models of learning that had been proposed formerly. Johnstone developed his model after many years of empirical measurement where he was studying learning in the sciences at school and university levels. It is, therefore, based on substantial empirical support. Later, he applied the model predictively in numerous ways, with considerable success. His paper of 1997 offers an excellent overview of this work (Johnstone, 1997).

Figure 2.2 An Information Processing Model (Johnstone, 1993)



One key feature in this model is that the perception filter controls the input and it operates on the basis of learners previous knowledge, prejudices, attitudes, beliefs, experiences and personal preferences. According to White (1988) selection of events plays an important role in learning.

2.7.3 Short-Term Memory or Working Memory

Short term memory is where we consciously think and process information and it is durable for very shorts periods of time. Ashcraft (1994) defined short term memory as a memory buffer or register that holds recently attended information. According to this view, short-term memory just holds information which has been selected from incoming information or has been drawn from long term memory. In other words, it is a static memory with limited holding time. More recently, researchers have described it as working memory (Baddeley,1999), because it is an area for performing various functions or operations as required.

In fact, evidence indicates that short-term memory plays two important roles: it is temporary information store and, at the same time, it is the place where processing of information takes place. In contrast to sensory memory, it receives information from internal links. Like the central processing unit of computer, it accepts translated internal language or encoded information from both perception filter and long term memory. Johnstone uses the phrase "working memory space" and this captures the dual function of this part of memory (Johnstone and El-Banna 1986). Working memory will be used here.

Miller (1956) found that there is a restricted capacity for this part of memory span and it can hold up just to seven (plus or minus two) pieces of information. In this paper, Miller presented the result of his experiments that he performed with adults. He repeatedly found that adults can only remember about 7 plus and minus two items at one moment. However, if the items are related, familiar or can be grouped together, they will be regarded as a one item and occupy less space. Miller named this process *chunking* and claimed that organising information into clusters will enhance the performance of working memory. According to Searleman and Hermann (1994) the working memory will improve if the pieces of information are familiar, frequent, related to each other.

Atkinson *et al.,* (1993) explained chunking as a means for using long-term memory to recode new material into larger meaningful units and then use those units, in working memory, as chunks. In this way, the capacity of working memory can be dramatically increased. For example, memorising a telephone number like 01413305172 is difficult in that the number of digits exceeds the working memory space. However, a person in Glasgow University would see this as: 0141-330-6565 where the first four digits are seen as one (the code for Glasgow), the second three as one (the code for the University), leaving only four more digits to be memorised. In this way an eleven digit number is chunked into, at most, six digits. Chunking facilitates learning but how to chunk depends on previous experience and is not easily taught.

Miller's description of 7 ± 2 illustrates the way in which there is variation between people. While the average working memory space is 7, most of the adult population have working memory spaces which lie between 5 and 9. Adult is defined in terms of age 16 or over in that the working memory space grows by about one unit for every two years up to age 16. The growth of working memory space almost certainly underpins the observed Piagetian stages of cognitive development.

It may be useful to give a more concrete if highly speculative information-processing description of the behaviour of the working memory. Imagine a computer which has limited-capacity buffers for each input device (but no ability to stop the device when the buffer is full). It also has a small number (like 7) of registers which can hold not input information but pointers to the buffers, and to long-term memory. The current input, for example the statement of a problem, will in some circumstances cause some of the registers to be loaded with pointers to parts of the long-term memory where procedures for solving the problem are stored. Other registers will point to the data for the problem. In other circumstances, where no procedures are known, the registers will contain nothing useful. Chunking can be thought of as the building in long-term memory of procedures linked together in such a way that a single pointer can access them.

2.7.4 Long-Term Memory

Long term memory is an area for durable storing. In contrast to short-term memory, it has almost unlimited capacity and is more or less permanent. The process of retrieval in this memory is not immediate as for working memory and it depends basically on how the information has been organised or represented. Most psychologists (eg. Atkinson *et al.* 1993) believe that forgetting from this part of memory is due to retrieve failure rather than lack of storage, and it would be unwise to deduce that the information have been lost for good. Although the information is probably there, it is not accessible. However, it is also possible that it was never encoded.

Attention, retrieval, and forgetting all play a part in the process of learning. The selected information passes from working memory to long-term memory and is stored for further recall (see figure 2.3). There are several techniques for improving the retrieval (Atkinson, *et al.* 1993). For example, there is rehearsal, pattern recognition, elaboration, organisation and clustering, chunking and imagery.

For easier recall, the information should be structured in well-organised way. Long-term memory is like a library and information is needed to be organised in a systematic way (Baddeley 1999). Adopting strategies to group the input in managable clusters or chunks during the process of encoding will enhance the retrieval (Johnstone and Al-Naeme, 1991). Rehearsal is another common strategy for enhancing the recall. We all know that elaborate items can be recalled easier: this is obvious as there is larger amounts of connections to increase the chance of retrieval. Imagery is another powerful tool for memory aiding. For example, we can recall easier a word, if we know what is its meaning. Mental images in some fashions can establish more connections.

It is suggested that there are three ways for storing items:

1) As disconnected items from any other learned material i.e. regarded as rote learning (Ausubel *et al.*, 1978)
2) As new ideas linked to existing knowledge in a rational way, making it richer, more interconnected, and accessible easily i.e. regarded as meaningful learning (Ausubel *et al.*, 1978)
3) As new ideas linked to old, but rationalised wrongly-the birth of alternative frameworks or misconceptions (Nakhleh, 1992).

Therefore, this again reconfirms the role of organisation, clustering and internalisation and interconnections between areas of knowledge.

2.7.5 Working Memory Overload

Earlier, the limitations of working space capacity were mentioned. Miller (1956) related these restrictions to what he called the 'magical number seven'. Many researchers developed his work further and provided more evidence for his findings. Among them, Baddeley (1986, 1992,1994) has contributed enormously to the understanding of working memory and presented a good description on the whole idea of how memory works.

Ashcraft (1994) describes the working memory as "the mental workplace for retrieval and use of already known information". Working memory operates two functions of holding and processing. These two functions exist in a kind of balance: if there is too much to hold, little processing can occur and if too much processing is required, it cannot hold enough. The more information to be held, the less processing can occur and vice versa. This is critical in learning a conceptual subject like Physics where considerable information is need to make sense of abstract concepts.

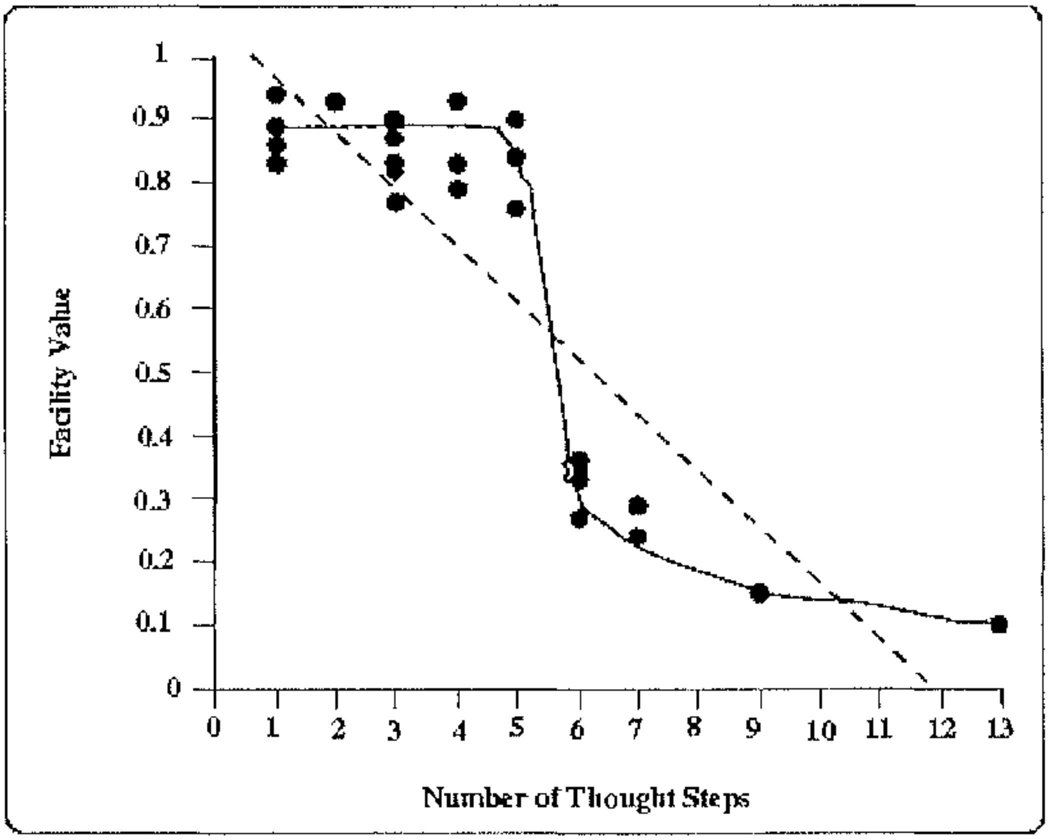
Kellet (1978) found that working memory overload ties in with lack of conceptual understanding. She found that school pupils can perform satisfactory for lower amounts of information, but their performance decreases with increasing the amount of input.

At a very early stage, Johnstone (1980) was interested in the relationship between learning difficulties and information overload. Johnstone and Kellett (1980) found that the main reason for difficulty in all the areas of science seemed to be working memory overload. They showed how learning difficulties can be reduced by applying chunking techniques. Deeper and better understanding develops chunking skills. It would seem reasonable, therefore, that teachers should apply chunking strategies by which students can reduce information overload and thus facilitate conceptual understanding. However, it appears that chunking skills vary from person to person and there is no easy way to develop such skills by simple teacher input (Johnston 1980).

Johnstone and El-Banna (1986) provided strong experimental evidence for the finite capacity of working memory space and how this limits performance very markedly. They investigated how pupils can handle chemistry problems with various levels of complexity. They attributed Z to the number of steps which is required to solve a problem and X to corresponding individuals working memory capacity. They chose the digit background test (DBT) and figure intersection test (FIT) to measure the working memory capacity of the students. They observed that for Z< X, the success is very high, but, for Z > X, the students have serious difficulty and success is very low. The graph of their results is shown in Figure 2.3. They used the phrase "thought steps" to indicate the memory demand of the questions where the phrase meant the number of facts, ideas or skills which had to be held simultaneously in order to solve the problem.

Figure 2.3 Performance and Demand (from Johnstone and Elbanna, 1986)

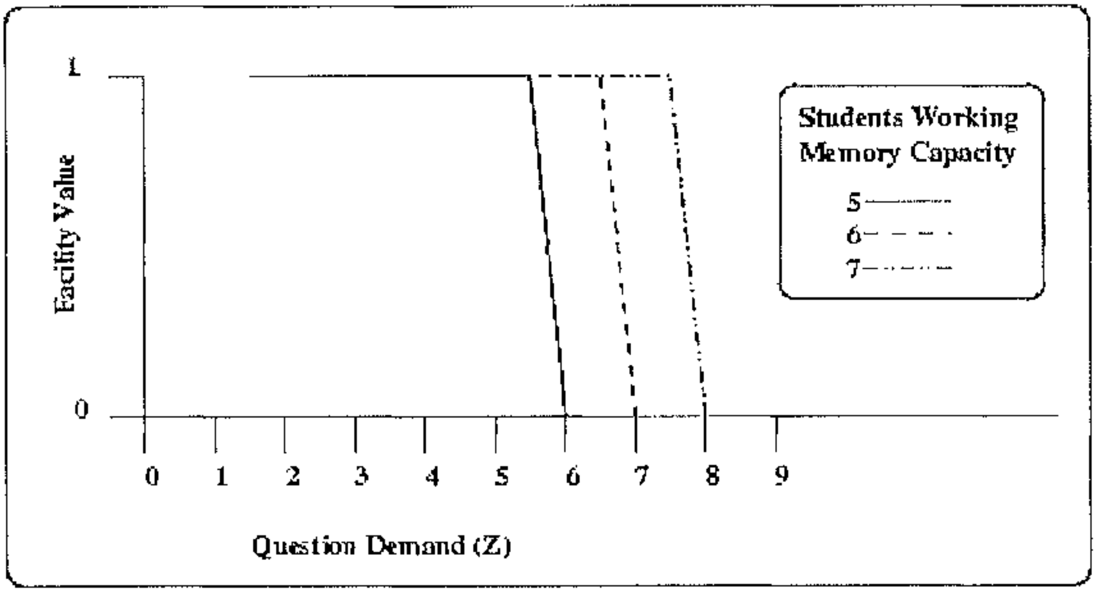
A plot of facility (proportion of students answering correctly) in objective chemistry questions versus the number of thought steps.



Originally, they expected to find some kind of linear relationship and they provisionally drew the best line of fit for their data. This is shown as the pecked line. However, they quickly appreciated that the relationship was not linear but was a cataclysmic fall as the demand level (Z) approached the limits of working memory space (X).

Following this, they divided the student group into three groups by their measured working memory space. They then obtained a set of three graphs which are shown diagrammatically in figure 2.4.

Figure 2.4 Diagrammatic Performance Collapse



Typically, in this kind of experiment, the drop tends to occur before the working memory capacity limit is reached. In addition, there is no perfect success at low demand levels nor total failure at high demand levels. The lack of perfect success at low demand levels shows that other factors causing failure are operating and success levels around 80% are typical. At high demand levels, success has dropped to around 20%. Johnstone suggests that students may be using some tricks, chunking strategies, or schema to operate on Z to make it less than X. They named these strategies Y . They noted that working memory capacity is not the only factor effecting a students performance and they added that, "the idea that Y includes pre-learned concepts which enables incoming ideas to be processed and meaningfully learned is Ausubelian" (Johnstone and El-Banna 1986). Overall, they demonstrated very clearly that, when working memory space is exceeded, performance drops dramatically. This has major importance in teaching a subject like physics.

2.8 Conclusions

In looking at the various contributions discussed in this chapter, Ausuabel emphasised the importance of previous knowledge and experience in influencing new learning. This is consistent with the ideas where knowledge and understanding are constructed in the mind of the learner. Piaget offered a new insight in his day in developing ideas that led eventually to the powerful understandings which have arisen from information processing.

This model has offer predictive insights in that it demonstrates why learning sometimes fails to occur when the amount of information to be processed at the same time exceeds the working memory space. In many topics in Physics, grasping a concept may depend on holding many ideas at once. This makes considerable demands on working memory space. In fact the Johnstone model brings together the ideas of Ausubel and the problems of working memory space limitations in a neat and accessible way. The difficulties in physics will be discussed in next chapter.

Chapter 3

Concepts in Physics and Difficulties

3.1 Introduction

Chapter 2 offered an overview of some findings from the educational research which contribute to the understanding of how learning takes place. However, it has become increasingly clear that there are serious difficulties in understanding the most important topics of physics. Over the past few decades, much research has investigated the problem in a systematic and scientific manner.

Cognitive psychology has offered many insights into the way the human brain functions when learning occurs. If a subject like physics is presented in a way that accords with the way the human mind learns, then the learning will be much more efficient and effective. Frequently, instruction in physics is inconsistent with some of the basic findings of educational psychology. This chapter looks at misconceptions and sources of difficulties in physics. It seeks to explore to what extent the cognitive models can be applied in teaching physics and what instructional strategies and educational frameworks should be adopted. The investigation has been focused on finding "what goes in the mind of the learner" to determine why the learner may encounter difficulties. In spite of all the difficulties, it is encouraging to see many physics students overcome all these obstacles.

3.2 Common Difficulties in Learning Physics

A wealth of individual pieces of research has been conducted, to investigate step-by-step students' reasoning with the fundamental concepts of Physics (McDermott *et al.* 1999). Unfortunately evidence indicates that, after instruction, most of the students at different levels and different areas of physics, have serious difficulties in learning physics (e.g. Crawley and Black 1992; Johnstone, 1991). It has been observed that even many of the undergraduates leave without altering their misconceptions (Duct *et al.* 1992 ; Wilson 1997 and Redish *et al.* 1997). Sometimes. they manage to pass the examinations successfully but they still fail to understand basic physical phenomena.

McDermott *et al.* (1999) argues that there is a limited ability to control all the variable sources of complexity in physics. However, the core of this chapter is devoted to overview some of the main well known and determined factors.

Many areas of physics are to be conceived in terms of mental models. Some types of models in physics represent a real existing entity that can be demonstrated experimentally, sometimes there are few clues of existence and some type of models do not represent any real or hypothetical entity such as the concept of ether (Smit 2001). According to Smit and Finegold (1995), students perceive that models should be a picture or exact copy of an object. This type of thinking may cause problems in some areas of physics.

3.2.1 The Sources of Difficulties at Early Ages

Driver *et al.* (1986) referred to a report of a survey that was carried out in England. This looked at school science and the report indicates areas of difficulties in certain areas of science and suggests the necessity of rethinking the teaching and learning of science.

In her approach, Driver *et al.* adopted a constructivist approach to curriculum development which takes into account the children's conceptions and their active construction of meaning. This approach implies that the mind constructs its own interpretations and conclusions. In this view, they suggest that the curriculum should be developed on the basis of former ideas and adopts a conceptual change view of learning.

Children usually construct their own beliefs and mini-theories about the nature, before they start their formal thinking. Much research (e.g. Driver and Erickson, 1983; Gilbert and Watts, 1983) provided evidence for this theory. This kind of thought is in accordance with the ideas of Piaget which has been outlined in chapter 2. Pupils usually adhere to their own beliefs and science teaching sometimes fails to change these ideas.

Moreover, sometimes the abstract nature of the curriculum content is beyond the learner's stage of maturity and this breaks Piaget's cognitive stages rule. For example, astronomy is a subject of study that starts from primary level. In the Scottish educational system (five to fourteen National Guidelines 2000) students at level A are supposed to link the pattern of day and night to the position of the sun. At level B, they should be able to relate day and night to the spin of the Earth. However, evidence shows that students have totally different theories for themselves.

Klein (1982) assessed the children's (7 and 8 years old) basic astronomy concepts, particularly their views about the day and night. He found many children have their own naive framework and do not have the perspective of the Earth in space and in rotation. According to Piaget, pupils at this age are in their concrete operational stage. At this stage, the child is able to relate his/her logical thought to what can be captured by senses and are not capable to develop concrete and abstract issues about shape and size of spatial objects that cannot be experienced. Furthermore, at this age it is hard to visualise the different kinds of rotation, and link all of this together to explain the phenomena of day and night cycle.

A series of studies [cited in (Thumper 2001)] has been conducted on the children and adults perceptions about shape, size, movement, temperature, composition and location of the Earth, Sun and Moon. According to these studies, many elementary school children do not hold a clear perspective of the Earth and Sun. Some imagine the Earth as a rectangle and some as a disc. A few of them imagine there are two earths, one flat that people live and another that is in the sky. Some others believe that the Earth is a hollow sphere with flat surface inside or flattened on the top.

They have different theories about the day and night cycle. Some believe at night, the Sun is covered by clouds or hiding behind the mountains. Some others think the Sun is located in a place which there is always day, and the Moon is somewhere that is always night and the Earth moves up and down between these two regions. Baxter (1989a) examined 9-16 years old children in England, with their basic concepts of astronomy understandings. Most of them related the seasons to farther distance between the Earth and sun in winter. Thumper (2001) implies this theory emerges from children's daily life experience that temperature decreases when he/she moves far away from heat source (Solomon 1983).

Furthermore, it has been noted that the images illustrated in textbooks do not adapt to the corresponding level of learner. For example, Martinez and Gail (2001) looked at the illustrations of the Moon phases in Primary and Secondary textbooks. Sometimes the textbooks use attractive photographs where usually the level of complexity is beyond the learners stage.

3.2.2 Teaching for Changing Concepts

Various models of learning are based upon the constructivist point of view, which regards learning as a conceptual change or conceptual development. To pursue this goal, science educators turned their attention to understand the mechanism of changing concepts. According to Scott *et al.* (1991), there are two strategies to promote conceptual change. The first perspective is finding a resolution for the conflicting ideas with a learner and a second is to generalise the existing frameworks. In the latter case, the instructor drives the learner's attention to establish the analogy relation between student's ideas and target (Scott *et al.* 1991). The strategies which stress the conceptual conflicts are in accord with the Piagetian notion of accommodation in which the learner is in central part and actively constructs its own knowledge. According to the Piagetian model of equilibrium, when the learner's existing models and concepts are challenged with new demands, cognitive development will occur to accommodate events which cannot be assimilated or which create some sort of cognitive conflicts (Shayer and Adey 2002). Piaget's (1964) interaction with the environment cognitive conflict and social interaction are contributors to construction of knowledge. Therefore these parameters together improve the development of a cognitive framework or schemata (Piaget, 1964; Henry and King, 1994). Thus, activities leading to cognitive conflict may be helpful to the process of changing concepts.

Some science educators lay a great deal of importance on cognitive conflict as a main factor of changing concepts in students (eg. Strike and Poser, 1985). Osborne and Wittrock (1983) stressed the thoughts that the learner brings to the learning environment. They added that the learner actively interacts with the environment and interprets his/her own meaning. Ausubel (1968), in his theory of meaningful learning, also argued that if new information can be linked to prior knowledge, it is more likely to be accepted. If the quality of these links are poor or prior knowledge is not scientifically accepted, there is a less chance for meaningful learning to take place, and this explains why science educators attached great importance to conceptual change.

3.2.3 Success in Algorithms but poor Conceptual understanding

Students often learn to remember formulae and practice how to apply the calculations, without knowing what is the underlying meaning. Usually before basic concepts are embedded, the curriculum moves on far beyond, and as a result basic concepts are overlooked. Kim (2001) carried out a survey on correlation between traditional problem solving and conceptual understanding. She found that students do not have serious problems in applying formulas, but at the same time they are poor in conceptual understanding. Her sample was 27 students who solved some 1500 problems successfully from the text books by Halliday and Resnick (1994) and Zemansky *et al.* (1984). A sizeable number of these problem solvers had significant difficulties in conceptual understanding. According to Kim (2001), there is a gap between the use of algebraic expressions and the associated physics concepts. In fact they do not solve the problems conceptually, but they adopt some strategies to deal with algorithms and calculations. Finally, she arrived at the explicit conclusion that although traditional problem solving is an important part of physics education, there are still some other aspects that might require further approaches.

McDermott (2001) reported the same problem. She asserted that facility in solving standard quantitative problems is not an adequate criterion for functional understanding. In fact assessments are testing the memorised algorithms. In this survey, she firstly probed students with quantitative question on single-slit diffraction. Then she tested them with qualitative question on single-slit diffraction. Although 70% determined the angle of the first diffraction minimum, the performance was poor for the qualitative question and only 10% gave a correct explanation.

3.2.4 Mathematical Language of Physics is Abstract

Usually physics is taught verbally *and* mathematically. The mathematical language of physics is too abstract and cannot be related to any common experience in life easily. Understanding physics through experiments and theorising, which builds links between equations and data, makes physics boring for many young people. For example vectors are preliminary tools for representation of magnitude and direction, but it is hard to visualise how a two dimensional vector represents three dimensional identity in vector product. Knight (1995) reported that sizeable fraction of university engineering students did not possess adequate knowledge about vectors.

More often students lack the level of mathematical proficiency required for learning physics and suffer from a lack of fluency in mathematics. According to Breiteberger (1991) even if the students are able to control or handle the sophisticated level of mathematics, still they are not able to understand it. The problem is that students are not able to relate the algebraic expressions to a physically meaningful expressions. In classical physics education, there is often no room for reasoning, conceptual thinking and dealing with premises.

Partial differential equation, linear algebra, numerical methods, curvilinear coordinates, spherical trigonometry, celestial coordinates, matrix algebra, spinors, tensors, complex variables, statistic and so on are all the pre-requisites for specific physics topics.

Breitenberger (1991) did a survey among students. On one part of his survey, he was looking to see if they were able roughly to describe the terms; Mobius band, Cantor set, Open sets, Topologies, Metric, Exterior, interior, Homomorphism, Norm, Completeness, Banach space, compactness. He found none of these terms made sense to them. So the students clearly are not prepared to deal with modern mathematics, for example: Lie groups or Hermitian operators in Hilbert space. According to Kim (2001), the actual procedure that is necessary to construct the concept is not specified and few students are successful at making connections by themselves.

Both research and teaching experience indicates that students are poor in reasoning and they treat Mathematics as a recipe (Breitenberger 1991). Breitenberger deduced that students are deficient in mathematics and their retrievable knowledge is elementary. Mathematics is a unified powerful language for the whole of physics, which can be regarded as a means to interpret the universe. Many students are not able to take advantage of this powerful tool and are not able to cope with advanced computer use. On the other hand, it should be noted that very great physicists like Faraday and Einstein, were not particularly knowledgeable in mathematics, so this implies that there also exists other means to explore the secrets of physics as Einstein (1879-1955) believed; "Imagination is more important than knowledge, knowledge is limited but imagination encircles the world".

One of implicit problems in the mathematical nature of Physics is the student difficulty in applying knowledge gained from one sphere (mathematics) to another (Physics). Transfer of learning has always been observed as difficult and some reasons for its difficulty have been suggested by Reid and Yang (2002).

3.3 Why is Physics Difficult to Learn?

The child starts to develop his/her ideas in a tangible world, but learning physics sometimes requires dealing with ideas which do not have physical or practical existence. Talking in abstract terms and dealing with concepts which only exist in the mind, without any tangible dimension, is not easy and requires higher skills and lots of mental energy. For example, electron, photon, crystal lattice structure, force and etc. are all ideas beyond the senses of learners. Children at early ages used to express themselves in their paintings, but when they are exposed to science learning even the images are the source of questions and concepts and need to be processed.

3.3.1 Multi Level Thoughts

Johnstone (1982, 1991) states that teaching science deals with both concrete and abstract concepts and it is a multilevel process. He described it as a multilevel thought process and demonstrated a triangle of multi-level thoughts (figure 3.1) with three corners which he described as macro, sub-micro and symbolic.

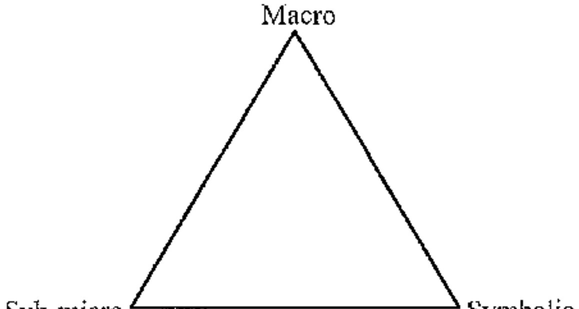


Figure 3.1

He noted that, in a science class, much of the learning takes place within this triangle, where the three levels interact in varying proportions and the teacher may be unaware of the demands made on learners. For example teachers try to take advantage of some macro phenomenon to describe the hidden aspects of the phenomenon, but the students can be stranded on the macro corner. Johnstone argued that it would be inefficient to present all three levels simultaneously to a young learner.

Although he developed his ideas initially for chemistry, he believed that there are three similar levels in physics: the macro, the invisible e.g. forces, reactions, electrons and symbolic (maths, formulae etc.). Electric circuits is a good example of Johnstone's multi level thoughts. This involves the symbolic part in the form of linear equations and Kirchhoff's laws, the macro that is voltmeter reading, current reading or interplay between different variables and microscopic level which deals with motion of charged particles, drift currents and fields.

Bat-Sheva and Uri (1990) analysed students reasoning about simple electric circuits. They probed students' understanding of macro-micro relationships and reasoning. They found that students operate properly in quantitative part (symbolic), that is dealing with algorithms and rote learning, the visible part (macro) was more difficult and the students were not able to see the system as a whole and interplay conceptually between the variables, but they worked it out for simple circuits. However, their performance was very poor when asked to explain the phenomena (macro) from microscopic level: in other words they cannot associate the microscopic concepts from electrostatics to the macroscopic phenomenon of electric circuit.

3.3.2 'Black box' an Explanation for Difficulties in Physics

Most early work related to the psychology of learning depended on a behaviourist perspective where it was not regarded as permissible to look inside the 'black box' of the mind. All that could be done was to observe what teaching took place and what behaviour (in terms of learning) emerged. This approach is now rejected and considerable research has taken place in an attempt to infer the mental processes which are occurring as learning takes place. Information processing has proved to be a most useful approach.

Information processing model is a powerful model to bring all the learning models together. It considers what the learner knows and determines what s/he will take in. The selective information is chosen on the basis of our previous knowledge, interests, prejudices, misconception and etc. (Johnstone 1997). Verbal transfer of knowledge can be a source of misconceptions, as students will just select the meaningful information.

The second function of black box of the mind which affects physics learning is when abstract physics concepts challenge the learner's thoughts. In this situation, the learner should be mentally able to manipulate the images in mind and sometimes in three dimensions. For example, in topics such as molecular structure or positional astronomy, the learner should have visual-spatial ability to visualise variety of structures and abundance of three dimensional spatial objects and their different forms of movements. When pupils are exposed to a two dimensional illustration in textbook or blackboard, they must construct their own interpretation and imagination and represent and manipulate their own spatial models. Interpretation is an extra task for working memory. However, there is a limitation on the space available for all this conscious processing (Johnstone and Al-Naeme, 1991) and all these demands may well be beyond the individual's mental capacity. Many psychological models represent the limitation of storage and retrieval of information through working memory (Sperling 1960) and in fact it differs from person to person.

In essence, by its very nature, Physics can often make considerable demands on a limited working memory space. This may be because of the abstract nature of ideas where considerable information and experience is needed to make sense of the concepts. It may be because of the frequent 'translations' between two dimensional representations of three dimensionsal situations. Indeed, it may arise as the learners struggle to work at the three levels of thought described by Johnstone. Whatever the reason, working memory space can be overloaded easily and the learner is reduced to some kind of memorisation process, with concomitant lack of meaning and intellectual satisfaction. Positive attitudes wane and the student opts for some other area of study which is perceived to be less demanding.

Johnstone never argued that the difficult themes should be left out. However, he did argue that care must be taken to present such themes so that demands on working memory space are minimised to allow for meaningful understanding of the concepts (Johnstone and Kellet 1980). In some areas, this requires considerable skill and imagination on the part of the teacher. At school level, it may mean postponing certain themes until the working memory space has reached a higher value.

It will mean allowing students time for the working memory to be cleared periodically as students pass and encode information into long-term memory, reducing working memory load and reducing the demands. Teaching may need to be divided into small sections and the use of advance organisers and examples drawn from the experiences of the learners will be useful.

In a fascinating experiment, lectures as a mode of teaching were explored (Johnstone and Su, 1994). In a lecture, students are bombarded with verbal data - a fast flow of information. They found that students actually recorded only about 10% of what the lecturer delivers. There is a transfer of information on to students' notepads but little evidence of understanding. It is also extremely inefficient in that 90% is not recorded. It is highly unlikely that all of the 90% was of no value.

3.3.3 Chunking

Until students have managed to 'chunk' information, it is very easy to cause working memory overload. Chunking encapsulates the information. A 'chunk' is what the learner perceives or recognises as a unit, mainly from his/her former experience (Johnstone and Kellet 1980). It can be a group of digits or a large number pieces of information combined to one unit, like taking advantage of date of birth to remembering bank pin codes and passwords, remembering a group of letters which are meaningful, a large number of words which can be chunked to a meaning, an experience with concrete objects, images or any other familiar experience which help us to handle the abundance of information easily. All these imply that remembering can be facilitated by meaningfulness. Thus, previous experience and meaningful concepts can support further understanding. The use of formulae in physics and mathematics is a chunking device as well. It brings all variables into one chunk. Chunking as a skill is idiosyncratic art, therefore, not easy taught. However, the physics teacher can make strenous effort to minimise potential overloads and suggest ways by which information can be chunked.

3.3.4 Explaining the source of difficulties with regard to the nature of subject

Numerous sources of difficulty have been noted, mostly related to overload in working memory which has not only to hold information but also to process it to make sense of it. Frequently, Physics can be taught using analogies. However, even here there are problems in that holding the analogy as well as understanding the Physics may lead to overload. Similarly, the use of mathematics alongside the development of ideas in Physics may have a similar effect. Sometimes the nature of a topic contradicts the beliefs that student had before: for instance; quantum theory and special relativity. In these cases students feel they had lost their experience of daily life as a chunking device. One feature of this difficulty appears in students' general frames of thinking. According to Schecker [(1981) cited in Niedderer & Schecker (1991)]:

> *"Students tend to see the task of physics in investigating single problems of the everyday-life world with sophisticated methods. They tend to work on theoretical and abstract problems by transferring them into one special situation of the real world. They are not oriented towards looking for abstract and general concepts and principles."*

Daily life and everyday experience can act as a chunking device for students to learn more easily. Quantum theory has been described as the "dynamic of micro level". By this, it can be understood that quantum theory accounts for the behaviour and energy of sub-microscopic particles. The problem is that the outcomes from quantum considerations do not relate easily to the experience of the first time learner. There is little in daily life that can be used to illustrate or exemplify the understandings which emerge from quantum theory. In addition, wave-particle duality is also counter-intuitive.

After teaching quantum mechanics for many years, Hood (1993) moves freely from macro level aspects of radiation to micro level, but that this is not easy for student who completes a typical introductory course. Hood believes students should distinguish that observed wavy aspect of light is just a macro level approximation of the random impacts of a large number of particles, which are governed by an underlying quantum dynamics. This a base concept and first step in learning quantum mechanics. However, this kind of reasoning would be highly demanding for students. The ability to reason in this way requires appropriate concepts and good prior knowledge of physics principles. Sometimes students lack the classical mechanics foundation that is a pre-requisite for quantum mechanics. Although quantum mechanics is different from classical mechanics in nature, both in its structure and its concepts, it relies heavily on understanding classical ideas. Since students are known to have serious difficulties with many classical concepts, even after instruction, some of the difficulties they encounter in learning quantum mechanics may be associated with weaknesses in their classical conceptions. Redish (1997) addressed some of these difficulties and approaches that may help students in this field.

Relating the concepts together from micro to macro, making analogy from abstract to concrete, requires holding two models at once and establish links between them at same time. All of these must be processed in working memory and that would be a high simultaneous demand on working memory space. Therefore, it is little wonder that there are steadily increasing reports (e.g. Bernhard, 2000 ; McDermott, 1993) finding that students are able to master algorithms and formulae, but they do not have a functional understanding and they lack the skill of reasoning.

3.3.5 Emotional and Cognitive State of Maturity

The emotionally mature physicist as perceived by Feynman can be seen from his following statements (Gribbin *et al.* 1997):

> *"In general we look for a new law by the following process. First we guess it. Then we compute the consequences of the guess to see what would be implied if this law that we guessed is right. Then we compare the result of the comparison to nature, with experiment or experience, compare it directly with observation, to see if it works. If it disagrees with experiment [or experience or observation] it is wrong".*
>
> *"In that simple statement is the key to science. It does not make any difference how beautiful your guess is. It does not make any difference how smart you are, who made the guess, or what his name is - if it disagrees with experiment it is wrong." (Gribbin et al. 1997, quoting Feynman)*

Richard Phillips Feynman who lived for the joy of discovery defined his achievements as the right attitude, the focus on nature's reality, the focus on asking the right questions, the willingness to try (and to discard) unconventional answers, the sensitive ear for phoniness, self-deception, bombast, and conventional but unproven assumptions (Anderson 1993).

These statements show us a kind of intellectual courage and confidence. Indeed, this reflects one aspect of learning which is often ignored: confidence. Such confidence comes from past success and offers to the learner a willingness to take cognitive risks when facing new ideas and demanding topics. As the students spend more times in physics, they may become more confident to encounter the reality and they will understand that a part of knowledge is willingness to learn and taking risks toward this end. When understanding does not come easily, they are self-assured enough that they will understand it in due course. The student who is emotionally mature will be exposed to the joy of science. This statement is in accord with a quotation from Henri Poincaré (1854 -

1912): *"The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful. If nature were not beautiful, it would not be worth knowing, and if nature were not worth knowing, life would not be worth living".*

Enjoyment of a subject and difficulty are not neatly related. For example, in one study it was shown that the most difficult parts of the work were often where student enjoyment was highest(Reid 1978). Overall, a student sense of satisfaction along with a growing sense of confidence are important in attracting and retaining students in physics as well as contributing to student success in learning. In her major study on attitudes towards physics, Reid and Skryabina (2000a,2000b) has uncovered and defined the key issues.

Student attitudes towards learning and what is required of them in learning Physics will also be important. These skills are associated with their style of learning and concerns the way they choose to extract material and ask questions and the method they apply to synthesise ideas. Elby (1999) found that some epistemologically naive students believed that success with algorithms constituted a full understanding and they did not have any picture of deep understanding. By contrast, cognitively mature students see physics as coherent and richly interconnected. Moreover he found that the students who adopt rote strategies believe that, if they focus on concepts and real-life applications, they will fail in their exams. A sizeable group of students think, even if deep understanding can lead to good grades, rote understanding can do so just as well. Students modify learning habits and rote strategies usually develop when the educational system rewards rote understanding (Schoenfeld *et. al* 1989). Sometime students attempt to understand conceptually but the pace of the course does not allow them to do so.

3.3.6 Learning Pathways and Experience

Education is a continuous process and information bombards our senses without stopping. Working memory processes some of this information for a short period of time. To become an expert in any field, information needs to be organised for easy retrieval and use. There is a sharp distinction between the student's way and the expert's way of understanding. Perception is the first process in human's processing (Clement 1998). The expert does not attend to all of the incoming stimuli. In other words, the expert's previous knowledge in long term memory controls their new learning.

Because of what they already know, the expert is able to select what is of interest or important or of greater impact. In this way, enough room in working memory is left for processing. The novice does not have the knowledge and well organised experience of the expert. Novices do not necessarily possess the schemata to organise and handle new information. Thus, part of their working memory will be occupied with processing of developing new schemata. For them responding to all stimuli would be a source of confusion.

This has been described as an ability to select the 'signal' from all the surrounding 'noise' (Johnstone *et al.* 1993). Previous knowledge and experience allows a clear focus on the signal and the working memory is not cluttered up with the noise. In addition, the previous knowledge has provided the expert with the skills to chunk new information meaningfully, again reducing pressure on working memory space.

3.4 Conclusion

Sizeable amounts of research have shown that serious conceptual difficulties exists in physics learning. Listening to lectures or success in solving standard problems would not be a case for fundamental understanding. A series of suggestions for ways of reducing these difficulties are:

To be aware of linguistic problems and the flow of information and avoid from working memory overload, decrease the level of abstraction and choosing an appropriate age for teaching different topic of physics. In addition a care should be take about the ideas and beliefs that students may bring in to class that may leads to misconceptions and misinterpretation.

Chapter 4

University Experiments

4.1 Overview

The overall aim of this part of the research is to investigate the feasibility of producing a body of material to assist students in diagnosing for themselves their understanding of physics in a way that is independent of the teaching they have received. The work done here should be considered to be a trial or pilot study for such a project. Two courses were explored - one at school and one at university. The latter is discussed in this chapter.

To find out which part of a university course on which to concentrate, a survey among students and lecturers in the first year Astronomy course was conducted. Two areas appeared to offer scope for a small scale study. These were Positional Astronomy and Special Relativity. The themes in each of these courses were listed and students were invited to indicate how they found these themes. They were offered four choices: easy, moderate, difficult, not studied. Where they indicated 'difficult', they were invited to say why.

Some care must be exercised against taking the students attitudes to a given topic too literally. Very often a student will think that something is 'easy' until faced by a question which tests understanding. Nonetheless, previous work with this kind of survey has indicated that student perceptions of difficulty match fairly closely with their performance in that topic (Sirhan *et al.*, 1999).

Having identified the broad areas of Positional Astronomy and Special Relativity, and some of their sub-topics as potentially fruitful subject matter, two pilot modules were devised and administered to student volunteers. In designing these modules care was taken to make the questions and their style independent of the lecture material; in fact, they were very different from the style of normal "physics-type" questions.

The aim was to allow students to see if they really understood the topic Thus, each question was designed to be answerable only if the student understood the basic ideas underlying the question, and not otherwise. The test was not whether the student could get the right answer but whether he or she could get any answer at all. None of the questions involved any mathematical manipulations.

After working through these modules the students were asked to fill in a questionnaire designed to assess their response to the module. A similar questionnaire was completed by the lecturers concerned, who were also interviewed informally about the work.

4.2 Survey Methodology

4.2.1 Identification of Courses

In the earliest stages of this work it was the lecturers in the Astronomy courses[1] who showed greatest interest in educational research. From informal conversation with them it emerged that the most promising courses within which to undertake this study were those in Positional Astronomy and Special Relativity. Positional Astronomy and Special Relativity are parts of Astronomy1X and Astronomy2 respectively. These subjects have the advantage, compared to others like stellar astrophysics, that they have a very narrow factual base and it is relatively less difficult for non-specialists to construct good materials. Paradoxically, they were the courses that the students seemed most comfortable with as a whole.

4.2.2 Identification of Topics

After going through the syllabuses and the textbook (Carroll and Ostile, 1996; Smart *et al.* 1997), reviewing the course, and consulting with the lecturers, the areas comprising the most important topics were identified. The practical experience of instructors gave a better insight into the process of selecting the right topics and constructing the questionnaire. A sample of these questionnaires can be found in Appendix A.

The survey was administered during the final class meetings of the first semester of 2002-2003. The students of positional astronomy were in the first semester of their studies in astronomy and there were 42 who participated in the survey. On the other hand, there were 17 in the special relativity class and they were in their third semester. The purpose

[1] In the University of Glasgow Physics and Astronomy is one department, though separate degrees in Physics and in Astronomy combined with Physics or with Mathematics are offered.

of the survey was explained to each class and the students were assured that they would remain anonymous. It should be noted that in positional astronomy the students were surveyed immediately before their exam. However, in relativity, the students were supposed to sit the final examination much later and they were perhaps not as well prepared.

Analyses of exam results in both cases show that the difficulties mentioned are well correlated with their exam performance. However, the sample size is not large enough to draw any strong conclusions.

In the first use of this approach to detecting areas of difficulty Johnstone *et. al* (1971) found that the methods for designing the questionnaire which are employed in the current survey are strongly reliable while the work of Sirhan *et al.*(1999) demonstrated validity. No further checks were therefore thought to be necessary.

4.3 Survey Results

Although the numbers of students involved were necessarily small (the classes were small), the survey offered a useful pattern of student responses. A later evaluation of examination papers confirmed the main findings while the lecturers involved also provided corroboration of the main findings.

For each course the results are shown as percentages of the respondents who reported a particular topics as difficult. The first column ('difficult') was defined as 'I still do not understand it'. The middle column ('moderate') is defined as 'I found it difficult but I understand it now' while the final column is 'easy' which means 'I understood it first time'.

4.3.1 Positional Astronomy

The student responses are shown as percentages of the sample (N=42).

	Easy	*Moderate*	*Difficult*
Terrestrial latitude and longitude	83	14	2
Great circle distance	71	26	2
Retrograde motion of planets	19	81	0
Lunar phase	26	69	5
Inferior and superior planets (inferior conjunction)	57	40	2
Greatest eastern and western elongation	16	67	12
Kepler's law	45	47	7
Alt-azimuth co-ordinate system	69	26	5
Practical problems with altitude- azimuth co-ordinates	19	61	19
The equatorial co-ordinate system	42	38	11
Transformations between different co-ordinate systems	**5**	**62**	**33**
Synodic and sidereal period	28	62	9
Diurnal motion	28	66	2
Seasonal change of constellations	26	69	5
Circumpolar stars	81	19	0
The tilt angle and the length of daylight	14	81	5
Equinox and Solstice	50	47	2
Mean sun	**19**	**54**	**21**
Spherical triangles	**23**	**52**	**23**
The Equation of time	**5**	**64**	**30**
Solar time and Sidereal time	**16**	**59**	**23**
Local and Greenwich sidereal time	19	66	14
Ecliptic latitudes and longitude	31	66	2
Mean solar times and different longitudes	12	71	16
The difference between noon intervals	38	54	5

The highest percentages for 'difficult' are shaded. These highest levels corresponded to Spherical triangles (23%), the Equation of time (30%), Solar time and Sidereal time (23%) and Transformation between different co-ordinates (33%).

The lecturer of the course indicated that transformation between co-ordinates and spherical triangles are inter-linked and it is expected to be similar in difficulty but it is interesting that students attached more weight with transformation between co-ordinates and pointed to it as the most difficult subject. The nature of the process of transforming co-ordinates requires a considerable amount of information to be handled by the student at one time and they need to move from one domain to another and establish links between two frameworks. This again provides evidence for overloading working memory space as a possible reason for difficulties.

The percentages show that students have no serious difficulties with different co-ordinate systems, when they perform each frame by itself, but the problem arises when they need to relate the two co-ordinates together. This requires holding two models at once and establishing links between them at same time. Both of these should be processed in working memory simultaneously.

The questionnaire also points to the fact that working with Alt-azimuth systems is regarded as easy. However, the students pointed out that it is difficult to deal with practical problems concerning Alt-azimuth co-ordinates. As has been reported repeatedly (McDermott, 1993), this is another example of student difficulty in developing functional understanding: they lack the skill of reasoning that is needed to apply the appropriate concepts in practical situations. Although the above mentioned subject shows only 19% difficulty, it might be worthy of further exploration.

The survey was carried out during the final sessions of the course. Thus, the topics: retrograde motion, lunar phase, inferior and superior planets, great eastern and western elongation, solar and sidereal period was presented in last days of the course and deemed to be easy by students.

Another problematic area is Solar and Sidereal time as well as the Equation of time. All these topics are highly dependent on the abstract concept of the vernal equinox. Here again, the amount of information required to make sense of these topics is considerable.

4.3.2 Examination Results

The degree examination for positional astronomy was carried out one week later after the survey was conducted. The description of the examination questions in positional astronomy has been presented below. In each question, a histogram of student performance is shown in Appendix B.

QA4 Draw a celestial sphere for an observer on the Earth's equator. Mark in the north and south poles, and the celestial equator. Mark the Sun's approximate position at noon on 21st December.

The question QA4 was a compulsory question about visualising celestial equator and tracing the position of the Sun on ecliptic. The question is worth 5 marks and the average mark was 3.2. In this question, there is a clear divide, with about 2/3 obtaining near full marks, leaving close to 1/3 getting it wrong. In the survey, 11% pinpointed this subject as difficult and 38% considered it moderate.

QA5 Explain briefly what is meant by the following terms:
nautical mile, sidereal day, local mean solar time, obliquity of the ecliptic, solstice.

QA5 was also a compulsory question worth 5 marks. The average mark was 2.7. According to the graphs of Appendix B, the distribution is almost square, but skewed to lower marks. About 50% were unsuccessful, confirming the survey. It should be noted that this question was concerned only with definitions.

QC1 Define carefully the co-ordinate systems of

(i) right-ascension and declination (α, δ); and
(ii) ecliptic longitude and ecliptic latitude (λ, β)

by drawing a carefully annotated celestial sphere showing the key aspects of each.

By considering the spherical triangle KPX for a star X, in which K and P are the ecliptic and celestial poles respectively, show that

$\cos\lambda\cos\beta=\cos\alpha\cos\delta$

Estimate the date when the Sun's ecliptic longitude is 45°. Calculate its right ascension and declination on that date. (Take the obliquity of the ecliptic as 23.5°)

[Sine formula: for the spherical triangle ABC, sin(a)/sin(A)=sin(b)/sin(B)=sin(c)/sin(C)]

QC1 was optional and it was about translation between equatorial and ecliptic co-ordinate systems on the celestial sphere. The average mark was 4/17. Most of the students (75%) achieved very poor marks. This confirms strongly the questionnaire results. Although the students were not aware of the problems when completing the questionnaire, but they were aware that the applications should be difficult. It should be also considered that this was an optional question and they had a chance to choose.

QC2 Give the definitions of great circle and nautical mile.
Two points A and B on the earth's surface have latitude and longitude (θ_1, λ_1) and (θ_2, λ_2) respectively. Show that the shortest distance d between these points is given by

$$\cos d = \sin\phi_1\sin\phi_2 + \cos\phi_1\cos\phi_2\cos(\lambda_1-\lambda_2)$$

An aircraft sets off from A on an initial bearing North East, with $\theta_1 = 52^oN$. After flying around a great circle path for 1000 nautical miles, it arrives at B. What is the latitude of B?
cosine formula: for the spherical triangle ABC, $\cos a\cos b = \cos b\cos c + \sin b\sin c\cos A$.

[Note that North East is the direction exactly between due North and due East.]

QC2 was also optional and it was about terrestrial applications of spherical trigonometry (distances on the earth's surface). The average mark was 8/17 and 41 students chose to do it, although 17 students performed very badly, 16 others performed reasonably well, of whom ten had almost perfect answers. Going back to the survey, it can be seen that 83% of students regarded this subject as easy. However, the exam result shows that they have problems in applying the concepts in practical situations.

Usually, examination results will give distributions of marks which are approximately normal, with varying degrees of skewedness. The graphs obtained here are not typical normal distribution. Patterns of marks which are far from normal may offer useful insights although it is outside the scope of this brief research to explore all these factors. However, graphs like this would suggest that the class contains two groups. One group might be those students who have a commitment to physics and/or astronomy and who made made more of an effort to gain understanding. The other group may involve students who are taking the course as an 'outside' subject and who are not so committed in that they see their future degree in another subject area.

4.3.3 Special Relativity - Interpretation of Results

The survey in special relativity gave the following results:

	Easy	*Moderate*	*Difficult*
nertial frames and Galilean transformation equations	5	94	0
How easy is it for you to accept the principle of relativity and constancy of the speed of light?	58	4	10
Lorentz transformations	29	70	0
Time dilation and length contraction	47	52	0
How difficult do visualise relativistic objects?	11	70	17
Velocity transformations of inertial frames	5	82	11
The application of transformation formula in relevant problems and shift between two frames?	0	88	11
Relativistic Doppler effect (Longitudinal and transverse)	11	76	11
Red shift and blue shift	41	58	0
Relativistic momentum and energy	5	88	0
Linear accelerated frames (free-fall)	35	64	0
Connection between free-fall and inertial frames	35	64	0
Concepts of inertial and gravitational mass (Weak equivalence)	5	64	29
Gravitational Doppler shift	11	64	11
Curved space-time	11	53	29
Geodesics	5	70	11
Relativity of simultaneity	5	88	0

Again, the highest difficult levels are shaded. Once more the results confirm that students were confident with algorithms of the Lorentz transformation, but they have difficulty to visualise the physical concept behind it. The results show that 17% of students were struggling with this concept and 70% regard it as moderate.

The results reveal the similar cause for the difficulties that again deals with transformation and shift between co-ordinates and application of formulas in real situations. Problem solving in real situations and applications seems to be dependent on the useful links between areas of knowledge (Reid and Yang, 2002). There is tendency for students to store knowledge in a compartmentalised way, like putting items of knowledge in a series of unrelated boxes. Meaning derives from the links between the "islands of knowledge" (Reid and Yang, 2002) and these links need to be well established moving in both directions between the islands.

Students claimed that they have no difficulty in the case of simultaneity while having difficulties in dealing with relativistic objects and relevant frames. This observation is in contradiction with other work. Scherr *et. al.* (2001) reported serious difficulty with the relativity of simultaneity. There is a conflict in the students' answers as well. It is impossible to understand simultaneity and at the same time have difficulties with visualising relativistic objects, so it seems that students were not aware that they did not grasp this concept. In this view, it would be helpful to confront students with cognitive conflict through a series of self-diagnostic tests. It was findings like this which led to the ideas which lay behind the development of the self-diagnostic materials.

These self-diagnostic materials were constructed to make students aware of their misconceptions. The problem will be more serious when students do not even know that they do not know. Students will improve their understanding while going through the self-correcting tests. According to Scherr *et al.* (2002), confrontation and resolution must be carried out by the student, not by the instructor if meaningful learning is to occur.

In the examination for Astronomy 2 held on June 2003, questions 7 and 8 were related to area of the current survey i.e. special relativity. Each Special relativity question mark was out of 20. The total exam mark was out of 100; the overall mark was also out of 100, but includes the exam mark (readjusted to 75%), laboratory mark (15%) and tutorials mark (10%). It is worthy to note that only 19 students sat in the exam. However, a few students did not do either of the special relativity questions as they did not have to, since they only had to do 5 out of 8 questions and several others did only one of them. The exam results are summarised in following tables. Table 4.1 is an unsorted data, but tables 4.2, 4.3 and 4.4, have been sorted in terms of total exam, Q7 and Q8 respectively.

> Q7 A light source flashes with proper interval Δt_0 between pulses. Show that the time interval Δt, measured between successive flashes by an observer (Albert) with respect to whom the source has radial speed u is
>
> $$\Delta t = \Delta t_0 \gamma + \Delta t_0 \gamma u/c$$
>
> Prove that Albert deduces the frequency, ν, of the pulsing source to be
>
> $$\nu = \frac{1}{\Delta t_0}\left(\frac{1-u/c}{1+u/c}\right)^{1/2}$$
>
> A long fast, spaceship approaches Albert on a collision course at constant speed. The front navigation lamps, known to be yellow (λ=580 nm) when berthed in space dock, appear violet (λ=400 nm) to Albert.
>
> *Continued overleaf*

Albert is astute enough to just escape the collision, and notes that the back end of the ship passes him 4.0×10^{-5} s after the front end.

a) What is the time interval as measured by stationary on-board observers, between the instants when the front and back ends reach Albert's position?

b) How long is the spaceship, as measured by these stationary on-board observers?

c) How long does Albert measure the ship to be?

Q8 In space time, what is meant by (a) a time-like interval, and (b) a space-like interval? Prove that for two events that are time-like in separation there ia always an inertial frame in which the events occur at the same spatial point, and that for events that are space-like in separation there is always an inertial frame in which the events occur simultaneously. Photons travel along null geodesics. Given the space time metric

$$ds^2 = c^2 dt^2 - e^{\alpha t} dr^2$$

in which α is a constant, show that photons travel along worldlines given by

$$\frac{dr}{dt} = \pm c e^{\alpha t/2}$$

Hence show that a photon emitted at t=0, $r=r_0$ will travel along a space time trajectory towards r = 0 given by

$$r(t) = r_0 - \frac{2c}{\alpha}\left(1 - e^{\alpha t/2}\right)$$

and will be detected at r=0, after a time $t = -\frac{2}{\alpha}\ln\left(1 - \frac{\alpha r_0}{2c}\right)$

Unsorted

Student	Q7	Q8	Total Exam	Total
1			60	67
2	20	12	72	76
3			56	61
4	0		22	35
5	3	10	53	59
6		2	16	28
7	2	6	26	29
8	15		62	65
9	1	0	10	17
10	4	6	45	49
11	17		82	83
12	16		66	72
13	4		42	48
14	0	1	11	29
15	20	13	79	80
16	4	5	54	61
17	13		66	69
18	4		50	59
19	6		70	73
Mean	8.1	6.1	50	56

Table 4.1

The question 7 and 8 are related to Lorentz transformation, relativistic Doppler effect and space time diagrams which are fitted in the area of the study and confirms the results of the difficulty survey, as the poor performance of the students shows a serious difficulty in this field.

Sorted by Total Exam

Student	Q7	Q8	Total Exam	Total
11	17		82	83
15	20	13	79	80
2	20	12	72	76
19	6		70	73
17	13		66	69
12	16		66	72
8	15		62	65
1			60	67
3			56	61
16	4	5	54	61
5	3	10	53	59
18	4		50	59
10	4	6	45	49
13	4		42	48
7	2	6	26	29
4	0		22	35
6		2	16	28
14	0	1	11	29
9	1	0	10	17
Mean	8.1	6.1	50	56

Table 4.2

Sorting the table by total exam marks shows almost a normal distribution presenting a complete stretch from 82 to 42, however, there is a slight gap between 42 and 26 that is not easy to interpret as the sample is very small and it may have happened by chance.

Sorted by Q7

Student	Q7	Q8	Total Exam	Total
6		2	16	28
3			56	61
1			60	67
15	20	13	79	80
2	20	12	72	76
11	17		82	83
12	16		66	72
8	15		62	65
17	13		66	69
19	6		70	73
18	4		50	59
16	4	5	54	61
13	4		42	48
10	4	6	45	49
5	3	10	53	59
7	2	6	26	29
9	1	0	10	17
14	0	1	11	29
4	0		22	35
Mean	8.1	6.1	50	56

Table 4.3

Sorting by Q7 shows a clear division between two groups either who can or who cannot answer the question. One group is over 13 and another below 13 and here is no score between 13 and 6. That is a classic distribution of a difficult topic. Talking to an experienced national examiner at school level revealed that this kind of distribution frequently occurred when the question is from a very difficult topic .

Sorted by Q8

Student	Q7	Q8	Total Exam	Total
19	6		70	73
18	4		50	59
17	13		66	69
13	4		42	48
12	16		66	72
11	17		82	83
8	15		62	65
4	0		22	35
3			56	61
1			60	67
15	20	13	79	80
2	20	12	72	76
5	3	10	53	59
10	4	6	45	49
7	2	6	26	29
16	4	5	54	61
6		2	16	28
14	0	1	11	29
9	1	0	10	17
Mean	8.1	6.1	50	56

Table 4.4

Q8 The results for Q8 do not convey much information because of the small number of students who attempted it. However, it can be seen that students have serious difficulty in this field and many of them avoid to choose this case and the scores of the number who did were not particularly good.

4.4 Exploring the Difficulties

In this section some of the sources of difficulty or confusion that lead to incomplete understanding will be explored. The discussion is intended to illustrate the way in which it is necessary to "think into" the subject before trying to construct correctional material. The discussion is not rigorous in the sense that every assertion has been verified experimentally. Indeed, these considerations might provide a potentially fruitful source of further research topics.

4.4.1 Difficulties in Positional Astronomy

There are many potential sources of difficulties in positional astronomy and many pitfalls and opportunities for working memory overload. The ancient language and misleading vocabulary can cause confusion for students. Unfamiliar terms or familiar terms changing their meaning can cause working memory overload (Johnstone 1984). For example, there will be considerable confusion in getting the meaning of altitude and latitude which usually stands for height and width but which, in spherical co-ordinate systems, are angles.

Sometimes, changes in meaning in two contexts can cause confusion for students (Harrington 1999). For example the *Equation of Time* is potentially a misleading term. *Equation* usually refers to a statement that two quantities are equal. However, the *Equation of Time* in astronomy is a *quantity* which specifies the difference between sundial time and mean solar time. The student is therefore required to bear in mind that this is a special use of the word *equation*.

Another contributor to difficulty is the fog of noise that comes with the signal. Noise is information that does not belong to or is not directly connected with the subject or matter being dealt. To the expert teacher signal and noise can be distinguished, but to a student separating the incoming signal from the noise is part of the process of learning. In this situation there may be a great difference between potential working space and usable working space (Johnstone and Al-Naeme 1991). Instruction, should cut out all extraneous noise.

Some definitions are needed in order to follow the discussion further.

The *celestial sphere* is a very large imaginary sphere centred on the Earth (or the Sun) on which all the heavenly bodies appear to be situated. The stars are fixed while the Sun, Moon and planets move along definite paths on the sphere as seen from the Earth. In reality, these bodies are at different distances from the Earth but observers are not directly aware of these distances. To a first approximation only the positions on the sphere are capable of direct measurement. The celestial sphere is an abstract construct and its use is justified only by its usefulness.

The *equator* is the projection of the Earth's equator onto the celestial sphere.

The *ecliptic* is the path on the celestial sphere traced out by the Sun (actually the centre of the Sun) as seen from the Earth. The Sun travels along the ecliptic and returns to its starting point once every year. The ecliptic is inclined at an angle of 23.5° to the celestial equator and it cuts the equator at two points. In the more correct (convenient) helio-centric view the Sun is motionless at the center of the celestial sphere and the ecliptic the projection of the Earth's orbit onto the celestial sphere, centred on the Sun, the 23.5° inclination arising from the tilt of the Earth's axis.

The two points at which the ecliptic (the path of the Sun) crosses the equator are called the *equinoxes;* because when the Sun is at one of them it is on the equator and day and night are equal in length. The date at which the Sun is at one of the equinoxes is also called an equinox. The vernal (spring) equinox, which occurs when the Sun crosses the equator from South to North, on or about the 21st of March, has special significance. Its position on the celestial sphere has since ancient times been the origin (zero point) of celestial co-ordinate. This gives rise to other potential difficulties. For example there is nothing in the sky to mark this important point; it is simply an abstractly defined position which in ancient times was near the beginning of the constellation of Aries, though it is not now, and hence was called the First Point of Aries.

The position of a celestial object is specified by two numbers which correspond to the latitude and longitude used on the Earth. Latitude is measured in degrees North or South of the Equator and longitude in degrees East or West of the meridian of Greenwich. The origin is thus the point where the Greenwich meridian crosses the equator. Positions on the celestial sphere are specified similarly but the latitude is called the *declination* and is measured in degrees North or South of the celestial equator, and the longitude is called the *right ascension* and is measured in *hours* from the vernal equinox (360 °) correspond to 24 hours). The celestial co-ordinate system is thus a grid printed on the celestial sphere just like the latitude-longitude grid printed on a map of the Earth. On the earth grid lines remain (approximately) fixed relative to the land masses, whereas on the celestial sphere the grid lines remain (approximately) fixed relative to the fixed stars.

In order to be able to make observations from the Earth it is necessary to use an Earth-bound co-ordinate system which specifies the *altitude* (measured in degrees) from the horizontal and the *azimuth* (measured in degrees East or West of the local meridian). The connection between the right ascension-declination system and the altitude-azimuth (alt-az) systems is time dependent because of the rotation of the Earth. A given star's right ascension and declination are fixed, but its altitude and azimuth change from one moment to the next.

Students need to be able to visualise both of these co-ordinate systems and, at the same time, be able to switch from one to other. This occupies extra space in working memory. To do this, they have to tilt the Earth back to upright, so that the Earth's North pole is pointing up and its South pole is pointing down. The Earth's North and South poles are tilted though with respect to the plane in which the Earth revolves around the Sun. Thus by putting the Earth upright in the celestial sphere and pretending that it is at rest, the Sun is now revolving around the Earth in a tilted plane. The inclination of the ecliptic is related to tilt angle of the Earth, but apparently attributed to the Sun. Visualisation of this is basic for further understanding.

Most of the problematic areas concerning solar and sidereal time and the equation of time are highly dependent on the visualisation of the celestial sphere and its co-ordinates. According to the questionnaire, it is easier to visualise the latitude and longitude than declination and right ascension. It would be very useful by analogy to extend the lines of latitude and longitude outward and print them on the celestial sphere to get the declination and right ascension. However, here is a potential for misconceptions as the reference points are different and the two systems are in continuous relative rotation. In addition, right ascension is measured in hours and not degrees.

The longitude is measured from the local meridian, but the right ascension is measured with respect to the vernal equinox. Students hold the perception that the reference point should be a fixed point in space or it should be referred to a solid object. They have a tendency to localise frames by the physical extensions of the objects that are fixed to them (Panse *et al.*1994), so here they treated the Sun as a reference, instead of the vernal equinox, and they are left stranded when the Sun leaves the point. How they should measure the right ascension with respect to vernal equinox and conceptualise the further concepts on the basis of hidden reference point. They need to keep track of vernal equinox when the Sun is not there.

Moreover, some kinds of configurations and rotations are very hard to visualise if the learner had not experienced that movement before. For example; gyroscopic procession of the Earth is very hard to visualise unless some useful metaphor can be found. Here taking advantage of a spinning top might help. The self-diagnostic tests should be designed so as to isolate the essential ideas.

4.4.2 Difficulties in Special Relativity

Although teaching special relativity makes a substantial break from Galilean relativity, both in its structure and its concepts, special relativity relies heavily on understanding inertial frames. Since students are known to have serious difficulties with many classical concepts, even after instruction, some of the difficulties they encounter in learning special relativity may be associated with problem of the influence of spontaneous ideas like the robust belief in absolute motion and time.

According to Panse *et al.*(1994), a frame of reference in students' alternative view is a kind of chunk of space tied to concrete body, bounded by the boundaries of the object. Moreover, they have a belief that frames of reference are concrete objects. There is an alternative conception in which a distinction is drawn between real and apparent motion. The real motion which has a dynamical cause and apparent motion which is a kind of optical illusion devoid of any physical reality.

The concept of reference frames forms a base from which other concepts in relativity develop. For example, reference frame is the heart of relativity of simultaneity and understanding the relativity of simultaneity is the key to understanding of special relativity but there are many difficulties in this field. The relativity of simultaneity is the central result of relativistic kinematics and consequence of Lorentz transformation. However, according to previous research (Scherr *et al.* 2000 and 2001) the undergraduates' misconceptions in this area are a matter of concern. Most of these difficulties can be traced back to common misconceptions with more basic underlying concepts such as reference frames. Many students believe that the time of distant events is determined by the time order in which signals from the events are perceived by an observer. The students tended to believe that events are simultaneous if an observer receives signals from the events at the same instant, in other words they imply that the simultaneity of events is determined by an observer on the basis of the reception of light signals. Moreover, they have a robust belief that simultaneity is absolute. Some students cannot relate the relativity of simultaneity to relative motion. There are students who fail to see the implications of the invariance of the speed of light and are not able to apply correctly the Lorentz transformations.

4.5 Self-diagnostic Modules

In what follows a preliminary study to prepare for a much bigger project is given. The two current diagnostic modules were designed in the areas of positional astronomy and special relativity as a pilot project. The aim is eventually to develop an extensive set of on-line materials which will allow students to assess their own conceptual understanding. The approach is directed towards the detection of misconceptions by exposing students to cognitive conflict and guiding them in the determination of their misconceptions and finding the resolution, and at this stage in paper form.

4.5.1 Positional Astronomy

This unit was focused primarily on concepts related to celestial co-ordinate systems and time. These topics having emerged from the survey as being 'difficult'. The unit was designed to probe the students' most basic understanding of the terrestrial origin of co-ordinate systems and of time. The underlying design principles for this unit were as follows:

(i) The students were to be confronted with the necessity of doing something useful without, initially, having the means at hand. Thus, they were not to use any previous knowledge of the constellations, for example. The idea here being to force the students to make connections between things that everyone should know (The sun rises in the East, for example) and the more abstract ideas of positional astronomy.

(ii) They were to be asked to come up with ways of achieving same definite outcome, rather than just give answers to factual questions.

(iii) The tasks should not be too far removed from reality.

(iv) Various hints and verbal prompts should be provided with the intention of helping students who get stuck.

With these principles in mind several possible sets of tasks (questions) were considered and rejected for various reasons. The main reason for rejecting a question or an approach being that it was two much like the content of a formal astronomy course and therefore not in accordance with principles (i) and (ii).

The idea of putting the student in the role of an astronomically ignorant, but otherwise intelligent, castaway with a pressing need to learn astronomy in order to increase his chance of rescue, suggested itself as a vehicle for presenting a more or less coherent series of tasks. Although it was nowhere stated explicitly the sequence of tasks very roughly mirrored what we understand to be the (pre-)historical development of the subject. This was commented upon by some of the students.

This use of an underlying 'story' appeared to be appropriate in this instance but that will not necessarily be the case in other areas of physics. The relativity unit to be described later makes use of it to a more limited extent through the sharing of background across a few questions only.

The narrative approach has the further advantage that it allows the development of a 'style' or 'tone' to the units. The Desert Island Astronomy unit has a deliberate and consistent light-hearted tone. There were two reasons for this: (i) To find out how students will respond; and (ii) to further separate the unit from the style of a formal lecture course.

For clarity, the unit is shown overleaf, with the spaces for student answers reduced in size.

Desert Island Astronomy

This exercise is a small prototype for a much more extensive one which itself forms part of the research being undertaken in the Centre for Science Education. The project is aimed at producing on-line, self-diagnostic learning material designed to help students assess their own grasp of difficult ideas.

Try to answer as many questions as you can. In some cases, hints are provided on a separate sheet at the back. If you use a hint, please be honest and indicate so in the box provided.

Preamble

You awake one day to find yourself alone on a desert island. You have no idea how you got there or what the date or even the year is. The island is apparently tropical, but you don't have any idea where it is; you are pretty sure that you are still on the Earth, though.

Fortunately, there is plenty of food (fish, coconuts, bananas, etc.) and water, and you don't need to spend too much time just keeping yourself alive.

Exploring the island you discover that others have been marooned there in the past and have left behind all sorts of things that might come in handy. The abandoned diary of a previous castaway seems to indicate that the most likely time for rescue is near the vernal equinox, when passing ships can sometimes be sighted - possibly something to do with the prevailing winds or currents. You are not entirely sure what or when the vernal equinox is, though.

Your Media Studies degree has not really equipped you for this situation, but you are intelligent and can remember some school geography and mathematics. You realise that you need to learn some astronomy to increase your chances of rescue.

After thinking for a few days you decide to make systematic observations of the Sun and stars. This is easy because the sky is almost always clear and the horizon is unobstructed. Choosing a broad flat area in the centre of the island as an observatory you mark a reference point with a suitable stone.

Explain either in words (briefly) or with a suitable diagram, or a combination of both, how each of the following self-imposed tasks may be accomplished.

Write your answers in the spaces provided

Task 1 - Get oriented.

(a) Establish the North-South line running through your reference stone (you will later realise that this line is called your local meridian) and mark its ends with stones. Explain how you did this. [Hint 1]

(b) Decide, using the motion of the Sun, which end of the line is North (remember, you don't know any constellations). Explain how you did this. [Hint 2]

(c) Establish the East-West line through your reference point and mark its ends with stones. Explain how you did this. [Hint 3]

Task 2 Observing the Sun over the course of a few weeks, you notice that its maximum altitude seems to change from day to day.

(a) Set up a simple apparatus in your observatory to help you record the variation in the Sun's maximum daily altitude. (Earth-moving and heavy lifting equipment are available if you need them.) Describe or draw this. [Hint 4]

(b) You gradually begin to recognise individual bright stars using the patterns formed by their neighbours. Out of curiosity you use your new observing apparatus to check on the variation of the daily (nightly) maximum altitude of the stars. What do you find?

(c) Two or three of the bright stars don't seem to have a fixed background pattern. This evokes a dim recollection. What is it? [Hint 5]

Task 3 While watching the stars at night you realise that they seem to revolve around a fixed point in the sky. You decide that this point must be the celestial pole that you remember hearing about.

(a) Using this circumpolar motion of the stars, check that you have assigned the correct names to the ends of your N-S reference line. Explain. [Hint 6]

(b) Modify your observatory so that when you stand at your reference point there is a fixed line-of-sight to the pole. Explain.

Task 4 You realise that knowing the location of the North or South celestial pole enables you to find the celestial equator.

(a) Modify your observatory so that there is also a fixed line-of-sight to the highest point on the celestial equator. Explain how this might be done. [Hint 7]

You decide to call the upgraded observatory "Stonehenge Lite".

Task 5 You can now study the motion of the Sun and stars in more detail. You discover two important things:

(i) the Sun is sometimes North of the equator and sometimes South of it;

(ii) any given star is always at the same angular distance North or South of the equator. They never cross the equator.

(a) Does (ii) agree with your observations in Task 2?

(b) What about the stars mentioned in Task 2(c)?

(c) How is (i) observed using Stonehenge Lite?

Task 6 It now becomes obvious to you that there will be certain days in the year when the Sun is on the celestial equator, and neither North nor South of it.

(a) A little thought convinces you that when this happens the hours of daylight and darkness will be equal. Explain this.

(b) It occurs to you that "equinox" must have some connection with "equal night". You are at last in a position to identify the equinoxes. Explain how to make a series of observations that will tell you that an equinox is approaching

(c) Having detected an equinox, do you yet know enough to predict roughly when the next one should be? Explain your answer.

(d) You are most interested in the vernal equinox (because that is when you hope you might get rescued). "Vernal" means "having to do with Spring". Do you now have enough information to decide whether any particular equinox is "vernal" (remember, you are in the tropics and there are no recognisable seasons) ?

(e) Pondering this problem, you think about history and geography and at last you realise that the vernal equinox occurs when the Sun crosses the celestial equator, moving from South to North. Explain how you came to this conclusion. [Hint 8]

Task 7 While awaiting the next vernal equinox, and the possibility of rescue, you extend your astronomical studies. By a piece of extraordinary luck you find in the remains of a wrecked ship a working clock. It is a "Smith's perpetually energised, perfectly accurate, astro-nautical Universal Time chronometer". It has no dial and no hands but it does ring a bell once a day at a time of the user's choosing.

You set the bell to ring when the Sun is on your reference meridian. Then on each subsequent day you use Stonehenge Lite to record the position of the Sun when the bell rings. You expect that these positions will simply move in a straight line along the meridian as the Sun's maximum altitude increases and decreases, but you find otherwise.

(a) Sketch the pattern actually observed. [Hint 9]

(b) Think of an explanation for this strange behaviour.

Task 8 Having amassed more than a year's data on the position of the Sun you can try to get some idea of your location on the Earth.

(a) How can you decide which hemisphere, North or South, you are in?

(b) How can you measure your latitude (a protractor is available)?

Task 9 Using your solar data (and the protractor) measure the Sun's greatest angular distance North and South of the celestial equator.

(a) Explain how you might do this.

(b) What is the answer?

After a few years at about the time of the vernal equinox, you sight a passing ship. You light your pre-prepared signal fire and the pirates come ashore and murder you.

Many years later, explorers visit the island and find the ruins of Stonehenge Lite. They conclude that it was used for primitive religious practices, probably involving human sacrifice.

Hints

If you use a hint, please tick the box for that hint

☐ 1. The Sun and stars attain their maximum altitude on the meridian.

☐ 2. The Sun and stars rise in the East and set in the West. When facing North, East is on your right.

☐ 3. The East-West line is at right angles to the N-S line.

☐ 4. Think sundial.

☐ 5. Wandering stars?

☐ 6. Is the rotation clockwise or anticlockwise?

☐ 7. Any line at right angles to the line between the celestial poles passes through the celestial equator.

☐ 8. The people who first thought of the vernal equinox lived in the Northern hemisphere.

☐ 9. The clock is running in step with "mean" solar time.

4.5.2 Task Analysis and the Results

Out of 42 students who completed the difficulty survey, twenty seven students participated in the assessment of Desert Island Astronomy. The survey was carried out in the second semester and some students had left the course by the time the materials were applied. The students' performance can be found in the table 1 Appendix B.

Students knew how to find the North and South direction using the pole star, but task 1 assumes that they are unaware if they are in Northern or Southern hemisphere and their knowledge in astronomy is very basic to use constellations and pole star, so it was a challenge to improve reasoning skills from very basic observations and they were asked to make use of the Meridian practically and to reason it out from the shadow plot. 57% of the students answered correctly. However, 40% failed to see that the location of the traveller is unknown and pole star does not appear in Southern hemisphere and they tended to solve the problem as they were instructed i.e. pole star. They can observe the sky and track the rotation of stars to see if it is clockwise or anti clockwise to deduce if they are in the Northern or Southern hemisphere.

Task 2 probes if students understand that the maximum altitude of the stars remain constant to a good approximation. Almost 85% of the students failed to see this, with just 15% answering correctly. After task three, the students' performance falls down markedly and from question three toward the end, almost none of the students were able to solve the tasks. From task 3 onward the module tries to visualise the concept of equator and vernal equinox by presenting a very simple device that is similar to "Stonehenge Lite" to keep the track of the sun. First they need to search for a line-of-sight to the pole (figure 4.1), so the line drawn perpendicular to this direction would cross the equator.

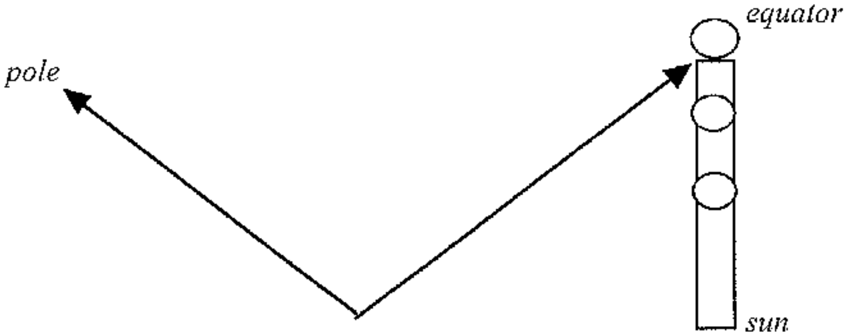


Figure 4.1 Visualizing the equator

By this means, they can trace out the ecliptic and observe the variations in the declination of the Sun. In the light of this experiment the student can see practically when the Sun crosses the equator. This will help to visualise easily the right ascension of any celestial body that would be the number of hours after the sun that the object passes the local meridian on the vernal equinox.

Even more by use of a clock, they can investigate the relations between the hours of daylights and the position of the Sun. The Sun is located on the celestial equator twice each year at the equinoxes, Students knew that the vernal equinox occurs on approximately March 21 and autumnal equinox occurs approximately about September 23, but here they should pay attention that there is no recognisable seasons in tropics. This exercise would be helpful to make a clear picture about the Sun's behaviour.

Task 6b probes if students are aware about the different behaviour of the Sun at vernal and autumn equinox. By observing the Sun through the Stonehenge-Lite's sight they can observe if the Sun moves Northward or Southward. If the vernal equinox is approaching the Sun moves Northward and if the autumn vice versa. Just one student answered correctly, and 40% of the students pointed to the length of day and night as an indicator to find which equinox is approaching. They did not mention how they can measure the day length without a clock. They just have access to the sundial that they have been made, but they did not mention how it can affect the sundial plot. They ignore that they do not have access to a clock until they find the Smith perpetually energised clock in task seven. These current self-diagnostic tasks already have shown that students do not have fundamental understanding to reason out in a new situation. They tend to think in the framework they have been instructed. In this way of thinking, they fail to see some of the conditions of the new situation. More examples of such tasks can be find in Physics by inquiry (McDermott *et al.* 1996).

In task 7a, students were asked to draw an analemma, i.e. a figure of eight pattern [which is Latin word for sundial (Murphy *et al.* 1997)]. This pattern results from the fact that the real Sun is sometimes ahead of and sometimes behind the 'mean' Sun, the difference at any instant being the Equation of Time.

All of the students are aware that the Sun is always due North at noon for an observer in the Southern hemisphere and always due South for one in the Northern hemisphere. However, in the tropics, i.e. between the latitudes of $\pm 23.5°$, the 'always' does not hold and the Sun is sometimes due South at noon in the Southern hemisphere. The fully correct statement is that the Sun is due North on most days for an observer in the Southern hemisphere, and vice versa. An observer on the Equator sees the Sun to the North and South or an equal numbers of days.

Many students stretch their curiosity to investigate the situation in Arctic and Antarctic circles. This task establish a link between alignment of the Sun and what can be experienced on the Earth.

By devising this simple device, equator would be an accessible concept to students. On this basis, many other concepts will come accessible as well. For example it would be easy to measure the latitude by finding the direction toward zenith and measuring the angle between zenith and the line of sight of the equator.

Finally in task 9 student can investigate that the greatest value of angular distance is 23.5 degree, by means of measuring the angular separation between the Sun and the line of sight of the equator. So it would be possible to directly measure the tilt angle simply. Reported hint usage is printed in table 2 Appendix B.

4.6 Special Relativity Unit

Unfortunately, a local holiday prevented access to students for assessing the special relativity unit. Instead, a sample of students was drawn from various sources: honours students who had already passed general relativity, a number of postgraduates doing PhD and a few second and third year undergraduates. The total number of students who participated in this assessment was 12. Although the sample was far from ideal, for the purposes of testing material which was designed to be diagnostic and to see if this purpose was being fulfilled in any way, the sample was adequate.

The design criteria were somewhat different from those adopted in the Astronomy unit. Here the intention was again to concentrate mainly on the most basic ideas but since in relativity there is no "do-it-yourself" operational context many of the tasks were somewhat closer to what might be found in an elementary course. The length-limited nature of the prototype was in this case a severe limitation. The unit is shown below, again with the spaces for student responses reduced in size.

Special Relativity

This material is designed not to test you (in this instance) but to help us to develop an extensive set of on-line materials which will allow future students to assess their own understanding of important ideas. Please try to answer as many questions as possible, even if you think that they have not been dealt with in your lectures - life is like that sometimes.

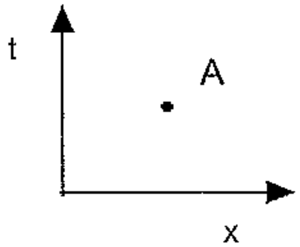
We will be making use of diagrams in (x,t) space. In order to be able to do so conveniently we will use convenient units in which the speed of light is 1.

Q1. If we wish to retain the second as the unit of time, we would take the unit of length as the second also. How could the second be used to measure the length?

Q2. If we wish to retain the metre as the unit of length, we would take the unit of time as the metre also. How would we then interpret the passage of 1 metre of time.

Q3. What, in these new units, would be the dimensions of a speed or velocity? Does this worry you or offend you?

Q4. The following diagram represents a point (an event) A in your frame of reference:



a) Draw lines on the diagram that represent the paths of light rays that originate at A (where a flash gun went off). Say why these lines, and no other, represent light rays.

b) You are situated at x = 0 (it's your frame, after all !). Can you ever see the flash? Explain.

In our convenient units the Lorentz transformation, ignoring y and z, is:

$$x' = \frac{x - \beta t}{\sqrt{1 - \beta^2}} \qquad t' = \frac{t - \beta x}{\sqrt{1 - \beta^2}}$$

where (x, t) are the co-ordinates of an event in your frame and (x', t') are the co-ordinates of the same event in a frame moving at speed b relative to you along the x axis.

Q5. Would it surprise you to learn that the Lorentz transformation was known and experimentally verified five years before Einstein's special theory of relativity was discovered?

Yes ☐ (So why is it called the Lorentz transformation?)

No ☐

Q6. Lorentz was led to the Lorentz transformation in the course of an enormously difficult, bravura analysis of the application of the laws of electrodynamics (Maxwell's equations) to the motion of a small sphere of charge (which he thought of as an "electron"). Nobody studies Lorentz's electron theory anymore.

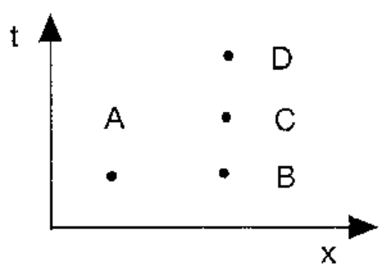
Einstein got the same result by making one easy-to-understand hypothesis;

(a) What was this hypothesis?

(b) Do you really believe it, deep down, in your heart-of-hearts?

(c) How would you go to about the convincing your mother that it really is true? (assuming that your mother lacks a deep understanding of physics; otherwise, pick any other suitable relative.)

Q7. The diagram shows 4 events, A, B, C, D , in your space-time frame.



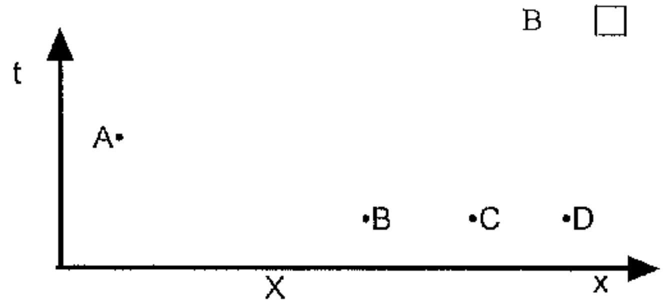
Event A is simultaneous with:

B ☐ C ☐ D ☐

Q8 . The diagram shows 4 events (A, B, C, D) in your space-time frame.

a) Which event(s) does the observer at X *see* as simultaneous with A?

B ☐ C ☐ D ☐



b) If the events A, B, C and D were flashes of lights emitted by flashers fixed in space, how could the observer at X determine their space distances from him or her?

c) Could he or she then discover which of the events really were simultaneous in his or her frame of reference?

Q9 Which of the following is (are) true ?

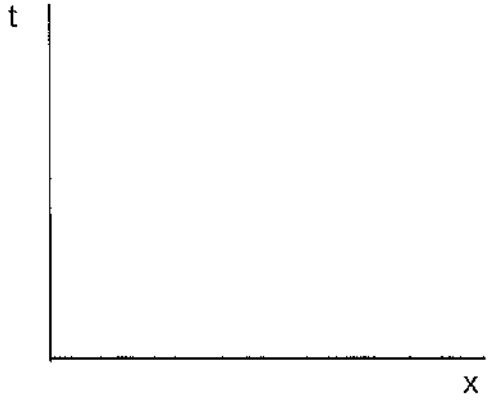
(a) The speed of light is the same for all observers.
(b) There is a quantity c (with dimensions of speed) which is the same for all observers and whose value is equal to the speed of light *in vacuo*

Does it matter? Is (b) just a nit-picking version of (a)?

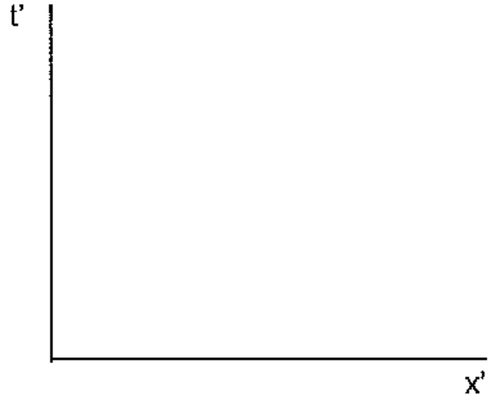
Q10 You could get the impression sometimes that relativity is all about rods and clocks. This is a 'rod' question.

In your frame, you have a stationary rod of length, L, with one end at x = 0 and lying parallel to the x-axis.

Draw the rod in the (x,t) diagram below, showing the paths of its ends.



Draw the rod in the (x',t') frame of an observer moving ***to the left*** relative to you at speed b.



Show on the diagram the ***length*** of the rod as seen by the moving observer.

Q11. Figure **A** shows a group of penguins standing on an iceberg. You are travelling past the iceberg in a very fast boat parallel to the line of penguins.

A 

Which of the figures B,C,D,E or F represents most closely the way in which the penguins appear to you?

B 

C 

D 

E 

F 

Q12. Ignoring the penguins, you study the iceberg itself. You correctly measure its size and mass in your frame; its size parallel to your motion has been Lorentz contracted, so its volume is decreased, and its mass has increased. Which of the following statements are true? Briefly explain your answers.

(a) The iceberg is denser in your frame than it is in its own frame.

True ☐ False ☐

(b) There is no disagreement about the height of the top of the iceberg above the water level as seen in the two frames. Why?

True ☐ False ☐

(c) The iceberg, being denser , sinks in your frame, but continue to float in its own frame.

True ☐ False ☐

If you answered TRUE to (c) estimate the consternation of the penguins (in both frames).

Q13. The penguins have become electrically charged (perhaps as a result of excessive preening).
Which of the following statements are true? Ignore any fields due to the earth or the boat.

(a) In their frame there is an electric field

True ☐ False ☐

(b) In your frame there is an electric field

True ☐ False ☐

(c) In their frame there is a magnetic field

True ☐ False ☐

(d) In your frame there is a magnetic field whose magnitude depends on your speed.

True ☐ False ☐

Q14. Your boat suddenly changes course so that it is now travelling at right angles to the line of penguins. A zoologist (who had been below being seasick up to this point) gets very excited and starts jabbering about "....penguin species previously unknown to science....".
What is be on about? How do you set him right?

Q15. You have always had trouble remembering formulae, particularly the signs.
When asked to write down the Lorentz transformation, you remember the general shape but not the signs. Which of the following really are Lorentz transformations?

A $x' = (x + \beta t) / (1 - \beta^2)^{1/2}$
$t' = (t + \beta x) / (1 - \beta^2)^{1/2}$ ☐

B $x' = (x - \beta t) / (1 - \beta^2)^{1/2}$
$t' = (t + \beta x) / (1 - \beta^2)^{1/2}$ ☐

C $x' = (x - \beta t) / (1 + \beta^2)^{1/2}$
$t' = (t - \beta x) / (1 + \beta^2)^{1/2}$ ☐

4.6.1 Task Analysis and the Results

Expressing time and space in the same units is convenient for describing relations among events in solar system and among stars and galaxies. It is also useful for describing motion of high-speed particles (Taylor & Wheeler 1998). Different units as meter, second, hour or year can be used for different situations. The constancy of the speed of light implies the central role of the speed of light as a conversion factor between time and space. As we are not accustomed to measure velocity dimensionless in Q3, the student were asked about their feelings toward dimensionless velocity. Almost all students responded that the dimensionless velocity sounds perfectly plausible to them. The students were confident with use of diagrams and 11 of them drew the paths of the light correctly that should emerges from point A and forms an angle of 45 degree with the x direction. but four of them failed to see that in space-time diagram at X = 0, the observer still moves in the time dimension and can see the flash.

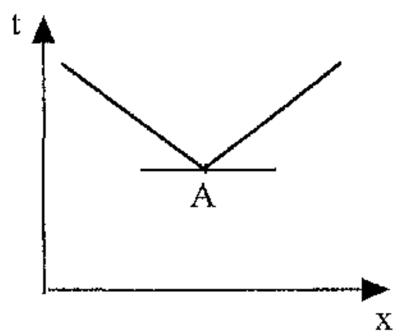


Figure 4.2

The rays of light cannot move backward in the space-time diagram as the time moves onward (figure 4.2).

"For most people the implications of special relativity are in strong conflict with their intuition" (Scherr *et al.* 2001). In the light of this, several questions were intended to discover students feeling about this subject. For example in question 5, most of the students imply that they were not surprised by the priority of the Lorentz transformation and moreover, they stated that the Einstein's postulates seem reasonable and believable.

Scientific language is not easily accessible to the public. There is no way for them just to trust the experiments. The problem is even more significant in a subject such as relativity.

The matter has been opened to dispute in question 6 part (c) of the special relativity unit. Q7 and Q8 probe if students distinguish between the events that are really simultaneous and the events which seem simultaneous. If two physical events occur simultaneously in one inertial frame they are not necessarily simultaneous in another frame. Only if they occur at the same time and at the same place they would be simultaneous in any other inertial frame. 10 students out of 12 answered correctly to find simultaneous events on the space-time diagram but less than half of the students failed to draw the paths of light rays from events A,B,C and D and check if they meet on the same time. The observer should account the time elapses for light to reach the observer.

Question 9 was devised to remind that the the Einstein postulate is valid for vacuum and care should be taken that light travels with different speed in different materials.

Most of the students were able to represent the stationary rod in space-time diagram (figure 4.3).

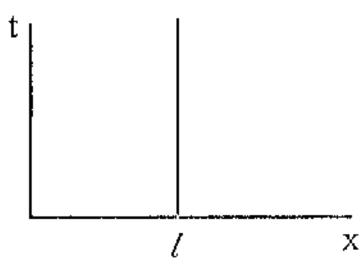


Figure 4.3

However, just 5 out of 12 demonstrated the contracted rod correctly in space-time diagram (figure 4.4). The length of the rod in the moving frame is the distance between its end at fixed 't' in that frame, and this is not the same as l.

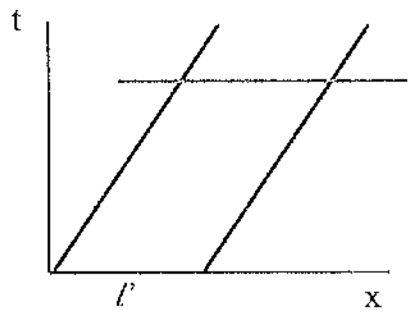


Figure 4.4

Relativistic moving objects are perceived to be contracted in the direction of motion. Q12 probes if students know that the object's perpendicular dimensions will not be affected. The logical explanation for this phenomena can be found in Epstein (2000). Students usually have seen Lorentz contraction for 2 dimensional objects and Gedanken experiments. Paying close attention to the problem the penguins are three dimensional and no more an abstract object, so one should consider the difference light travel times from different parts of an object and objects may seem rotated. The concept of a rigid body has no place in relativistic mechanics. However, this was not the intention to confront the students with contraction of 3 dimensional objects, so by inserting an additional statement i.e. asking about the approximate figure of penguins, the 3D effects were ignored.

According to an interview with the lecturer of the course, the penguins' tests were more qualitative in nature rather that be quantitative. As outlined above, it was not the intention of designing this question to explore how the Lorentz transformations works in real world, but the lecturer considered it instructional to show the 3D aspects of relativity, to show not only the geometry involved, but also that the difference in time travel from different parts of an object should be taken into account.

The survey has shown that relativistic Doppler shift was one of the moderatelydifficult topics. Half of the students failed to see that the penguins will be Doppler shifted in question 14 and the relativistic observer will see them with different colours. Our imaginary observer looks excited to discover new species, the same situation may happen in astronomy. For example red galaxies are more common but sometimes galaxies appear in different colours that can be caused by its speed and direction of the moving body.

Q15 was devised to examine if students can recognise Lorentz transformations. The formulas consist of many symbols and signs and are not easy to remember. Many students picked equation B, which is not correct. It would be easier just to remember that denominator has a minus sign in between and numerators of x' and t' are symmetric in changing the place of x and t. Knowing this fact, can be used as a chunking device to remember the equation.

4.7 Measuring Students' Attitudes

Attitudes express the evaluation of the study and the feeling toward all aspects of the study. These may influence how the students will learn that topic or whether later they choose to continue with that study.

Attitudes are not directly measurable but can be deduced from behaviour. Several methods can be employed to measure the attitudes. There is no certainty that any specific method is perfect. Each method has its own advantages and disadvantages, so it is necessary to use several methods.

The evidence shows that a well-designed questionnaire can provide extremely accurate insights in to how students think and the way they evaluate situations and experiences. If a questionnaire is carefully constructed, reliability will be enhanced (Reid, 2003). In such a well-constructed questionnaire the reliability can be deduced easily from the pattern of the responses.

The methods presented here arose form the work of Likert (1932) and Osgood *et al.* (1957). Previous research (Sirhan, 2000) has shown these methods are strongly reliable. In the Likert method, possible questions are gathered and responses follow the pattern like strongly agree, agree, uncertain, disagree and strongly disagree. The validity is taken as a face validity, judged by the views of a few experts.

In the Osgood method, opposite pairs of statements are gathered and the position of the ticks between the word pair shows the scale (usually six points scale) toward one of the ends. The ease of the construction and quick answering are the advantages of this method. Again, validity is taken as a face validity, judged by the views of a few experts.

4.7.1 Questionnaire Employed for Positional Astronomy

After completing the Desert Island unit, students were given a questionnaire to be completed the same day (Appendix B). The questionnaire was designed to explore students' perceptions of the effectiveness of the Desert Island Astronomy unit and to measure their attitudes toward positional astronomy in general. Question 1 was designed using Osgood's method while questions 2 and 3 followed Likert's method.

Questions 4 and 5 were open ended questions about their background in positional astronomy and their attitudes toward the material. Questions 1 and 2 were designed to seek their attitudes toward positional astronomy. The questionnaire is shown below, with the responses shown as percentages.

Positional Astronomy

All Data as %
Sample: N = 27

(1) Tick *one box for each line* to show your opinion:

Positional Astronomy is

Straightforward	0	8	44	33	11	4	Complicated
Boring	4	19	15	48	11	4	Enjoyable
Too mathematical	0	4	19	56	19	4	Not too mathematical
Experimental	4	4	15	30	41	7	Theoretical
Hard to visualise	15	15	41	18	7	4	Easy to visualise
Clear	0	19	26	33	19	4	Confusing

(2) Tick the box which ***best reflects your experience*** of positional astronomy:

	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
I found the subject full of complicated language	0	22	26	44	4
There was too much information to absorb	0	15	15	67	4
I found it difficult visualise what was happening	4	41	26	26	4
The idea of the vernal equinox is difficult to visualise	4	4	22	41	30
It is difficult to understand celestial co-ordinates	7	26	30	33	4
I find thinking in three dimensions very hard	4	26	19	37	47

(3) Thinking about ***the material you have just completed,*** tick the box which best reflects your experience;

	Strongly agree	Agree	Disagree	Strongly disagree
The material helped me to spot the areas where I had difficulty	11	63	19	4
The hints which were offered were useful	0	70	22	4
I can 'see' some of the ideas behind better now	4	30	63	4
I did not have enough time to complete it properly	44	41	11	4
I liked the style of the questions	4	41	37	15
I understand things better now	0	44	44	11
It simplified the ideas for me	0	48	41	11

(4) **The most difficult aspect of positional astronomy, in my opinion is**

Difficulties in co-ordinate systems and transformation (10, difficulties in practical situations (2), visualising difficulties (5), spherical trigonometry (4), calendars and times (2), connecting different parts and use efficiently from all the information (2), old fashion language (1), too descriptive and not factual (1), rote learning (1).

(5) **The most helpful part of the material I have just completed was**

Addressed practical situations, simplify difficult subjects, I understand that I need more to understand and how actually is complicated (3), putting theory in to experiment, refreshed ideas in my mind, the module build up one on another,using basics knowledge (32), one pointed to the way ancients think, imagination helped me to understand better (more visualised) (2), one pointed to better visualisation of spherical co-ordinates, vernal equinox visualised, being murdered.

(6) **The plan is to extend the material and place it on the web so that future students can seek help when they want. Please suggest any ideas to make this as helpful as possible**

put more examples (3), one pointed about co-ordinates, more clarification (2), more hints (2), animation and diagrams and graphics (5), put questionnaire and friendly printer option on internet, put answers, it would be helpful for people missing the lectures.

The data for each question will now be discussed in turn.

(1) Positional Astronomy is

Straightforward	0	8	44	33	11	4	Complicated
Boring	4	19	15	48	11	4	Enjoyable
Too mathematical	0	4	19	56	19	4	Not too mathematical
Experimental	4	4	15	30	41	7	Theoretical
Hard to visualise	15	15	41	18	7	4	Easy to visualise
Clear	0	19	26	33	19	4	Confusing

The students views appear quite realistic. For example, they find the topic quite theoretical and hard to visualise. Encouragingly, it does not appear to be excessively complicated, confusing nor mathematical. However, levels of enjoyment are not very high.

(2) Tick the box which best reflects your experience of positional astronomy:

	SA	A	N	D	SD
I found the subject full of complicated language	0	22	26	44	4
There was too much information to absorb	0	15	15	67	4
I found it difficult visualise what was happening	4	41	26	26	4
The idea of the vernal equinox is difficult to visualise	4	4	22	41	30
It is difficult to understand celestial co-ordinates	7	26	30	33	4
I find thinking in three dimensions very hard	4	26	19	37	47

Results show that students were very optimistic about their understanding and not aware about the problems they have in this field. Both the exam results and the survey showed that they have serious difficulties in the grasping the concept of vernal equinox and 3D visualisation. Moreover, they are sometimes confused by language as mentioned earlier in the case of the equation of time and altitude.

(3) Thinking about ***the material you have just completed***, tick the box which best reflects your experience:

	SA	A	D	SD
The material helped me to spot the areas where I had difficulty	11	63	19	4
The hints which were offered were useful	0	70	22	4
I can 'see' some of the ideas behind better now	4	30	63	4
I did not have enough time to complete it properly	44	41	11	4
I liked the style of the questions	4	41	37	15
I understand things better now	0	44	44	11
It simplified the ideas for me	0	48	41	11

Question 3 measured their attitudes toward Desert Island astronomy. 74% of the students stated that the material pinpointed the areas of the difficulties. This was encouraging in that was the main goal of designing the self-diagnosic unit. It was satisfying that a few students expressed that they understood their weaknesses that they were not aware before.

(4) **The most difficult aspect of positional astronomy, in my opinion is**
Difficulties in co-ordinate systems and transformation (10, difficulties in practical situations (2), visualising difficulties (5), spherical trigonometry (4), calendars and times (2), connecting different parts and use efficiently from all the information (2), old fashion language (1), too descriptive and not factual (1), rote learning (1).

The results of the question 4 confirm the difficulty survey. Students reported their difficulties in transformation between co-ordinates and spherical trigonometry.

(5) **The most helpful part of the material I have just completed was**
Addressed practical situations, simplify difficult subjects, I understand that I need more to understand and how actually is complicated (3), putting theory in to experiment, refreshed ideas in my mind, the module build up one on another,using basics knowledge (32), one pointed to the way ancients think, imagination helped me to understand better (more visualised) (2), one pointed to better visualisation of spherical co-ordinates, vernal equinox visualised, being murdered.

In question 5, students' attitudes toward the unit sound promising and in accord with the goals of the study. For example they pointed to applications in practical situations, pinpointing the misconceptions using basic concepts, thinking as ancients scientists do and the construction of a mental picture.

(6) **The plan is to extend the material and place it on the web so that future students can seek help when they want. Please suggest any ideas to make this as helpful as possible**
put more examples (3), one pointed about co-ordinates, more clarification (2), more hints (2), animation and diagrams and graphics (5), put questionnaire and friendly printer option on internet, put answers, it would be helpful for people missing the lectures.

It should be noted that developing a series of self-diagnostic body of materials is not intended to be a replacement for lectures or other forms of teaching.

4.7.2 Questionnaire Employed for Special Relativity

The special relativity questionnaire was designed to explore students' perceptions of the effectiveness of the unit and to measure their attitudes toward this topic. The number of students participated in survey was 12 and this is not large enough to draw any firm conclusions. Because of the small number of participants the results are not expressed in percentages and just showing the number of people who ticked each box. The original questionaire is printed in Appenix B and one with the results can be found below.

Special Relativity

All Data as Numbers
Sample: N = 12

(1) Tick *one box for each line* to show your opinion:

Relativity is

Straightforward	0	1	1	4	3	3	Complicated
Boring	0	0	1	3	4	4	Enjoyable
Too mathematical	0	0	2	6	2	2	Not too mathematical
Hard to visualise	2	2	4	2	2	0	Easy to visualise
Clear	0	1	3	4	2	2	Confusing

(2) Tick the box which ***best reflects your experience*** of special relativity:

	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
I found the subject full of complicated language	0	0	4	6	2
There was too much information to absorb	0	2	0	8	2
I found it difficult visualise what was happening	3	6	1	2	0
I found the concepts strange	2	5	2	3	0
It is too far from reality	1	1	1	5	4

(3) Thinking about ***the material you have just completed***, tick the box which best reflects your experience:

	Strongly agree	Agree	Disagree	Strongly disagree
The material helped me to spot the areas where I had difficulty	3	6	3	0
I can 'see' some of the ideas behind better now	2	4	5	1
I need more time to work on it properly	0	8	4	0
I liked the style of the questions	4	6	1	1
I understand things better now	1	2	9	0
It simplified the ideas for me.	0	5	6	1

(4) The most difficult aspect of special relativity, in my opinion is

Einstein Postulates (5), Lorentz Transformation (2), Space time (4), Transformation frames (1), Subconscious level and visualisation (3)

(5) The most helpful part of the material I have just completed

Five people pointed to penguins and the density of the icebergs, one of them claimed that she has never thought about the effect of relativity on density, students were happy that the module refreshed their knowledge and it was a challenge for rethinking.

(6) The plan is to extend the material and place it on the web so that future students can seek help when they want. Please suggest any ideas to make this as helpful as possible.

Programme animations of showing relativistic objects as the case here with Penguins, more extensive quantities of current materials, using real situations such as particle physics along with analogy puzzles.

(1) Relativity is

Straightforward	0	1	1	4	3	3	Complicated
Boring	0	0	1	3	4	4	Enjoyable
Too mathematical	0	0	2	6	2	2	Not too mathematical
Hard to visualise	2	2	4	2	2	0	Easy to visualise
Clear	0	1	3	4	2	2	Confusing

(2) Tick the box which ***best reflects your experience*** of special relativity:

	SA	A	N	D	SD
I found the subject full of complicated language	0	0	4	6	2
There was too much information to absorb	0	2	0	8	2
I found it difficult visualise what was happening	3	6	1	2	0
I found the concepts strange	2	5	2	3	0
It is too far from reality	1	1	1	5	4

Questions 1 and 2 are measuring the attitudes toward special relativity. In question 1, the trend is toward complicated and confusing but, enjoyable. In question 2 students went for strange concepts, hard to visualise.

(3) Thinking about ***the material you have just completed***, tick the box which best reflects your experience:

	SA	A	D	SD
The material helped me to spot the areas where I had difficulty	3	6	3	0
I can 'see' some of the ideas behind better now	2	4	5	1
I need more time to work on it properly	0	8	4	0
I liked the style of the questions	4	6	1	1
I understand things better now	1	2	9	0
It simplified the ideas for me.	0	5	6	1

Question three is asking about the module that they completed. This part of the questionnaire designed again on the basis of Likert method and the students view about the module was quite positive. The most promising part was that again module was successful in its goal to spot the areas of the difficulty.

(4) The most difficult aspect of special relativity, in my opinion is
Einstein Postulates (5), Lorentz Transformation (2), Space time (4), Transformation frames (1), Subconscious level and visualisation (3)

(5) The most helpful part of the material I have just completed
Five people pointed to penguins and the density of the icebergs, one of them claimed that she has never thought about the effect of relativity on density, students were happy that the module refreshed their knowledge and it was a challenge for rethinking.

(6) The plan is to extend the material and place it on the web so that future students can seek help when they want. Please suggest any ideas to make this as helpful as possible.
Programme animations of showing relativistic objects as the case here with Penguins, more extensive quantities of current materials, using real situations such as particle physics along with analogy puzzles.

Questions 4,5 and 6 were open ended. Most of the students found it difficult to believe the constancy of light's speed. This is while 11 students answered that they can believe it in question 6. Most of the students expressed that they have difficulties with handling space-time diagrams.

Most of the students were happy with the module, they stated that the module refreshed ideas in their mind, challenge them to think and help them to sketch an image that is not forgettable. 5 students found penguins the most helpful part and they expressed it was the first time that they thought about relativity and density.

In question 6 students asked for a greater number of such a materials and they proposed to add computer effects, animations and simulate relativistic objects by computer. One of the students suggested that analogies should come along with real practical examples such as the practical application of special relativity in particle physics.

4.8 Conclusion

The two experimental pilot units developed here were surprisingly well received by both the students and their lecturers (see Appendix B for the lecturers' responses). Very few responses were critical of the units and those that did criticise did it in a highly constructive manner. Since the aim was to test the students' understanding in such a way that lack of understanding was revealed automatically it was gratifying that a number of students reported that this had indeed happened.

These two units were necessarily small in scale, so that they could be completed in a class hour. This imposed severe limitations on the didactic power of the units. The Special Relativity unit was done by a relatively small number of students, some of whom were rather advanced in their studies. Even these students reported that the unit had been of benefit.

The general approach used in each unit, whereby the most basic elements essential to the understanding of the topic were emphasised, has been shown to be appropriate. Further development along these lines is thus encouraged. A second edition of these units, not length-limited as these were, would include more hints and more tasks aimed at making sure that fundamental misconceptions were corrected so as to provide a more secure foundation for later tasks. For example, the relativity unit, as presented, did not involve enough examples of the type of Q7 and Q8 which were aimed at the distinction between what is and what seems to be simultaneous and these should be more inbuilt pointers to the right answers, as in Q12(c), designed not to provide the answer, but to show that there is another way of looking at the problem.

This experiment has been encouraging and will serve as a good foundation for further work. It has provided evidence that more developed, more extensive on-line self-diagnostic materials can be profitable to students.

Chapter 5

School Experiment

5.1 Overview

The work with the university students suggested that, while the students could master the use of algorithmic approaches to learning so that they could often pass examinations, they often had difficulty in really understanding the material being taught. It was thought that the same problem would be likely to exist at school level. Students of that age might not, however, be able to cope with the kind of diagnostic material employed with university students. A slightly different style might be appropriate where the school pupils would have to apply their knowledge in social applications.

Traditional instruction is on the basis of teacher-centered learning. Collaborative group working is an alternative to this approach. From one stand of view collaborative group working can promote cognitive conflict (Kalman *et al.* 1999). Conceptual change can occur during the collaborative discussions and students may have the opportunity to hear different views from the members of the group. This may be regarded as another way of a constructivist approach.

For this purpose, material was developed, for a group working approach based on the Britain's primary energy resources. Energy is known to be a difficult topic (Zapiti, 1999). The intention was to allow pupils to be confront difficult issues and decisions relating to energy.

The unit developed was based on a unit originally produced for university level (Watt, 2002). His original unit was designed for physics students with the main aim of allowing them to interact with issues related to the workplace where physics might have a major contribution. For school use, the original was edited and simplified, following consultation with an experienced physics teacher who had offered a large sample of his pupils for testing purposes.

The structure of the unit involved group working of a role playing nature and it was thought that this would be helpful to prepare students to gain the skill of working co-operatively in groups. This would be a valuable skill as, in practice, they would need to team up to confront the problems of real life. The unit also attempted to develop personal skills, social and scientific attitudes.

Due to the time restrictions in gaining access to the school pupils, it was not possible to determine the students' performance in answering the questions raised in the unit. However, after working through the unit, the students were asked to fill in a short questionnaire designed to clarify their reaction to the module and their attitudes towards the topic of energy.

Before describing the unit, it is worth looking at the place of role play approaches in terms of what is known about student learning.

5.2 Role Play Techniques and Educational Outcomes

Science and society are becoming interconnected increasingly. From this standpoint, it has been argued, in the context of England, that the school science curriculum is in need of significant revision (Osborne and Collins, 2000). In the present day, scientific education is not intended just to produce professional scientists but to engage learners with their society and culture. Citizens need to contribute to their society and science education should respond to the basic requirements of daily life of the education consumers. The curriculum developers should consider the scientific knowledge, personal skills and attitudes that needed to be developed for dealing with everyday life.

In most countries the science curricula are overcrowded as advances have introduced new topics and themes without removing content which might be considered less important. Teachers are forced to move rapidly through the syllabus and pupils resort to note copying and memorisation to achieve examination success. There is only a limited time to do a science course in schools and there is inadequate time for in-depth discussion. There is little value in copying down from overhead or blackboard without have a chance to ask and to think. In fact, learners are not active in the process of boring writing (Osborne and Collins 2000).

Pupils often perceive that scientific topics are irrelevant to their lives and they attempt to learn it not as a matter of intrinsic interest but for career advancement (Osborne and Collins 2000). The curriculum content has failed to develop the attitude of regarding science as a way of thinking and the ability of modelling abstract systems. This way of thinking can produce a generation where school science is seen as the province of the minority and has little relevance ot those not involved in scientific jobs.

Writing in a Scottish context many years ago, Johnstone and Reid (1979) argued that, in addition to understanding the science, science education should include the following aspects:

(1) Development of scientific attitudes
(2) Development of social attitudes related to science
(3) Development of personal skills and communication skills

Their work laid great emphasis on the development of social attitudes related to science. In this, teaching units were developed where the school pupils had to interact with problem situations where they had to apply their science in order to reach socially acceptable solutions. For example, in one unit, they had to select fibres for specific market demands and then relate the fibre properties to the polymeric structures (Reid, 1977). In another, they had to plan for the development of a production unit, taking into account raw materials, usage demands, scale and the geographical context (Reid, 1999).

Developing such social attitudes related to curriculum content is also likely to increase perceived relevance on the part of pupils and, in an experiment involving 1100 school pupils, they were able to demonstrate that this was achieved (Reid, 1980). Of greater importance, they obtained evidence that attitudes were developing. The attitude development was very often along the lines that pupils were developing viewpoints which were soundly based on evidence and they were able to argue cogently to support their view.

The unit being discussed here was designed to copy the features which had been shown to be successful in attitude development. Thus, for example, by reflecting on the contemporary issues of the society in a scientific context, science can be presented as relevant to the present and future. The importance of understanding the science then becomes more apparent and the study of physics is not just seen to be useful just for passing the exam: physics actually relates to life.

Research in social psychology (Meg 1992 cited in Ratcliffe 1997) has shown very clearly the power of role play in attitude development. Reid took these ideas into an educational context and has discussed the place of role place in the teaching of the sciences (Reid, 1980).

Much later, Solomon (1990) pointed out that even competent students have difficulties to cross over from the domain of life world knowledge that is needed for socio-scientific debates to that of formal scientific knowledge. Students and even teachers have not taught in this way and they may feel a lack of confidence (Johnstone and Reid, 1979).

Another feature of the unit was its use of group work and the place of group work is now discussed briefly.

5.3 Group Working and Communications Skills

Evidence has indicated that group working promotes learning (Grant, 1978). Solomon, (1992) emphasised that small group discussions can be helpful to construct a well informed society. Acquiring communication skills and learning how to cooperate with others are both important social skills.

The possible reasons why cooperation may foster learning can include various factors. As outlined previously, working memory overload is one of the crucial factors that causes the difficulties in learning in conceptual areas. In a group problem solving, pupils can 'share' their working memory space to handle different parts of the problem. Of course, the working memory space of each pupil is unaltered. However, by sharing tasks, the potential for individual overload is reduced.

In addition, members of a group can share their experiences and more questions may be raised. In this situation, different cognitive structures may be adopted to approach the problem. One of the problems in all learning is lack of confidence and the fear of being seen to be inadequate. In a group, individuals can 'hide' in the group identity and this may encourage the growth of confidence and the willingness to take cognitive risks (Reid and Yang, 2002).

There are many social advantages in working in groups as individual learn to cooperate, to overcome language barriers and to learn how to help each other. It is a mature skill to be able to bring many ideas together, to draw on diverse opinions and suggestions in order to arrive at a conclusion. This is particularly important in a topic like energy which is known to be difficult.

5.4 Difficulties in Teaching and Understanding the Concept of Energy

As outlined in chapter 3, the ideas and expectations that students bring into class are of great importance. There is now a considerable concern for the alternative frameworks that usually leads to misconceptions (Maskill *et al.*,1997). Alternative frameworks is a general expression which describes the existence of widely held ideas which may diverge considerably from accepted scientific understandings.

This problem is common in a topic like energy. In everyday life, pupils may hear about the idea of energy but not in a strict scientific sense. In fact, these misconceptions can be traced back into the society around us. Energy is often associated with moving bodies or technical instruments. For example, Solomon (1983) notes that the sentences 'wool is warm' or 'I am energetic today' are such a highly robust notions that cause students to think in two domains: the symbolic domain and life-world domain. In other words, pupils have conceptual ideas which are part of daily living and the scientific understandings are developed separately.

Solomon suggested that the fluency of movement between these two domains determines the level of understanding. Because learners spend most of their time in everyday situations and communication, the life-world realm understanding dominates. Thinking in two domains, of course, can cause working memory overload. Also there is a common confusion that energy, heat and temperature are similar (Maskill and Pedrosa, 1997). In everyday language heat, warmth and cold are terms that are related to the sensations.

Transfer of energy is a matter of confusion. A well known firm belief is that energy is like a kind of fluid that travels inside bodies from one to another (Maskill and Pedrosa, 1997). Moreover, energy may not be considered as a conserved quantity. Kaper and Goedhart (2002), noted that conservation of energy in everyday language means 'not to waste energy'.

Various terms used for different forms of energy and transferring from one state to another can be a source of difficulty and working memory overload. Kaper and Goedhart (2002) argued that energy is not a tangible object but a mathematical abstraction which can just be experienced logically. However, while energy is certainly intangible, it is not really just a mathematical abstraction. It can be sensed and its effects can certainly be experienced. If energy is taught at a young age as something which enables things to happen (a layman's version of 'capacity to do work'), then this picture is consistent with much normal experience. The mental model also has the advantage of focussing the young learner on the outcomes which may be highly tangible.

5.5 Methodology

5.5.1 Describing the Unit

The unit is in several parts. The first part is an introduction and assumes that students are in year 2004 . It attempts to give insights into the problems of energy of Britain in 2004. As part of the European Union, Britain has to conform to the Renewables Obligation which insists that the country sources a minimum of 10% of its energy from renewable sources by 2010, such sources being defined somewhat idiosyncratically. The problem for the pupils is how to achieve this, given limited budgets. In this, they are effectively being invited to be energy consultants to government and adopting this role.

The second part is an overview and introduces the different renewable resources and discusses energy losses, maximum theoretical efficiency and practical efficiency. The key part of this section was to take into consideration the issues that usually emerge from technological limitations. The efficiencies of two kind of turbines have been compared in this section and the intention is to give an idea about the numerical amount of efficiency in practice. The attempt is to clarify the idea of efficiency in energy transformations and understanding the fact that inefficiency is inevitable. It has to be noted that pupils, at this stage, have not met the idea of entropy and the Second Law of Thermodynamics. Nonetheless, the pupils are invited to list the likely sources of inefficiency in harnessing various energy sources.

In a group of three pupils, one pupil is now given briefing paper 1 which deals with fossil energy and solar energy. Pupil 2 studies a briefing paper 2 on hydro energy and wave energy while the third pupil has a briefing paper on tidal, nuclear, wind energy. After a time for reading, thought and, perhaps, some calculation, each pupil adopts the role of advocate for the source of energy studied. Each teaches the other two group members about the energy sources studied and present arguments for and against these sources. Sources which are not regarded as renewable are included for comparison in that it is important to develop sources which are cost-effective compared to those currently used.

As a group, they have then to reach some kind of decision. In this, they are acting the part of scientific advisers to government. Overall, each group has made a feasibility study that led to developing a strategy and policy making by each group. The teacher acts as Secretary of State for Energy. They present their conclusions using one OHP slide. In doing this, their ideas about energy may be clarified. At this stage, all groups are able to interact with each other and compare conclusions. In this way, the key issues may stand out and indirectly lead to a deeper understanding of the physics behind the material. The full unit is shown in the Appendix C.

5.6.2 Describing the Procedure

The study was carried out towards the end of the school year, after studying the topic. in total. 100 students were drawn from several schools in England, organised through one school. The pupils were aged about 15 and were studying for a GCSE in Physics. students had completed the unit which took about an hour, they were given a questionnaire to be completed immediately. 97 completed questionnaires were received. The questionnaire was designed to explore students' perceptions of the effectiveness of the unit and to measure their attitudes toward the topic of Energy. The original questionnaire can be found in Appendix C.

Renewing Energy

(1) Tick ***one box for each line*** to show your opinion:

Studying Energy supply is

Straightforward	3	11	27	14	24	21	Complicated
Boring	30	24	17	21	5	2	Interesting
Irrelevant to me	17	12	31	22	13	4	Relevant to me
A meaningful experience for me	3	10	23	20	19	24	A meaningless experience for me
Hard to visualise	21	14	22	31	8	4	Easy to visualise
Clear	6	15	14	22	22	21	Confusing

(2) Tick the box which ***best reflects your experience*** of ***energy*** (as a topic you have studied):

	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
I found the the study of energy full of difficult ideas	15	50	22	12	2
There is too much information to absorb	30	46	10	12	2
The study of energy has made me more aware of pollution	5	33	28	30	3
The idea of energy is far too abstract	3	19	55	21	2
There are too many forms of energy to grasp in one go	10	46	15	27	2
The study of energy is not relevant to my life	8	20	37	27	9
It has helped me to use energy more efficiently and economically	0	22	31	33	14

(3) Thinking about ***the material you have just completed,*** *tick the box which best reflects your experience*:

	Strongly agree	Agree	Disagree	Strongly disagree
The material helped me to spot the areas where I had difficulty	7	51	42	1
I think I am more aware of the importance of the issues raised	4	56	36	4
I can 'see' some of the ideas better now	11	60	27	2
I did not have enough time to complete it properly	16	52	29	2
Compromise between economics and pollution is important	4	70	26	0
I do not like the style of the material	12	48	40	0
I understand the economic and political energy debates better now	5	47	42	5
I understand the meaning of energy better now	9	48	40	3
Working as a group helps me to understand better	15	67	17	1
Working in a group is a very important skill for my life	23	60	10	8

(4) **The most difficult aspect of studying energy, *in my opinion* is:**

33% of students reported that the difficulties they have in this topic is related to the huge amount of information. A sizable number of students stated that they are not able to understand it at all and they explained that they had difficulties with equations concerned.

(5) **The most helpful part of the material I have just completed was:**

10% of students found it helpful to work in groups. 20% of studnets indicated that the unit provided a good overview on the different forms of energy and specially renewable energies. Students also mentioned that unit made them aware of social aspects of the topic.

5.6 Discussion of Results

Because the units were applied in schools distant from Glasgow, it was not possible to observe the pupils taking part. However, a verbal report from the teacher who coordinated the work indicated that the pupils thoroughly enjoyed the experience but found it very difficult. In particular, attention was drawn to the introductory section where they had to pinpoint specific aspects of sources of inefficiency. This moved beyond the syllabus taught to them and it was indicated that they had not coped well.

Questions in section 1 asked students about their general experience about the topic of energy supply. It is very clear that pupils views about the this tend to be negative. A sizeable number of students stated that the topic is boring, irrelevant, and hard to visualise. Confirming previous studies related to energy itself, many pupils found the topic complicated and confusing. The sad observation is the number of pupils who tended to see the topic as irrelevant and meaningless. Energy is one of the fundamental issues of life and of global importance even to the extent of influencing national and international policy. Its importance in looking at such diverse areas as daily lifestyle, travel and leisure cannot be underestimated.

Within typical physics curricula at school level, the ideas of energy are often developed in a fairly abstract way and it would seem that many of these pupils were not perceiving the relationship between their physics studies and the importance of the concept in making sense of many major issues of life.

As expected, the questions in section 2 show a fairly negative experience. Energy usually is regarded as a difficult topic. These results are consistent with previous researches in this field (Zapiti, 1999). It can be seen in the results from the second and fifth parts of section 2 that there is there is too much information to absorb and there are too many forms of energy to grasp. This reaction is typical of student views when there is working memory overload.

The pattern of results tends to confirm the way energy is taught as a fairly abstract idea, and pupils do not see its relevance to lifestyle. However, it is interesting to note that the pupils' reaction to the abstractness is neither negative nor positive. At this age, pupils are cognitively developing the skills to be able to handle abstract ideas better. In final question of section 2, students' general views about social implications of energy were examined and again it is sad that so many seem to fail to apply it in their lives.

Section 3 sets out to explore the effectiveness of the role-play unit This is quite encouraging in that the teaching unit seems to have generated some positive perspectives. In particular, the first part indicates that one of the purposes of the unit was being fulfilled for slightly over half of the students: they were being enabled to see places where they had difficulty. This was paralleled by their responses to the third and eighth parts where they indicated that the unit had helped them to grasp ideas better.

There were negative features. For example, the format of the unit was not universally applauded and, clearly, it was difficult to complete in the time allowed. Of course, the units was adapted and simplified from a unit originally designed for level 1 university physics students and the structure perhaps demanded a higher level of social maturity than that to be expected from 15 year olds who had still to sit their first national examination in Physics.

In section 4 and 5 again students reported about the huge amount of energy to absorb. On the other hand, they expressed their very positive views about the group working. This is consistent with the evidence from previous research already discussed briefly. It is a feature of much teaching at both school and university level that most of the teaching is formal and teacher centred. Lectures dominate at university while, at school, formal teacher-directed work is typical. There is frequently inadequate opportunity for group work where the students are offered opportunities to interact with each other and with subject matter in such a way that ideas are exchanged, concepts are explored and understandings are challenged in, hopefully, a fairly unthreatening setting.

5.6 Some Conclusions

Originally, this study was planned to focus on university students. The opportunity arose to extend it to some school pupils and it is interesting to note that many of the features observed for students are also evident with their younger counterparts. Too much cannot be made of a very short survey at the end of one unit. However, it can be seen clearly that no meaningful learning occurred and difficulty in this topic is a matter of concern. In this case active participation of students in the process of learning enhanced learning. Collaborative working can provide students with cognitive conflict through interaction with the group and the group as a whole has a larger space available for working memory. The group working ccourages students to express their ideas and enhances learning.

Chapter 6

Conclusions and Further Work

6.1 Summary of the Study

The whole study was an experiment essentially neither to measure students' knowledge at this stage nor to evaluate the lectures or traditional method of instruction. The intention was to examine an alternative approach in teaching and learning which is based on active participation of learner with special emphasise on conceptual understanding of the basic concepts. The attempt was to produce a body of minds-on activities and motivational tools that can be served as self-diagnostic tests to promote the meaningful learning of physics. This kind of approach has had roots in the constructivist view of learning that has been emerged from Piagetian theories. The experience here showed that there is a serious difficulty in grasping basic concepts and qualitative reasoning. This implies once again that the foundation stone of the building of knowledge that is understanding of the basic concepts has been lost as usually happens in most occasions in traditional style of teaching and learning.

6.2 University Experiments

Totally university experiments comprised of three parts; difficulty survey, astronomy units experiments for promoting functional understanding and measuring attitudes toward the topic before and after students worked out through the units.

6.2.1 Conclusion from Survey

Students addressed difficulties in some areas of special relativity and positional astronomy. It was quite surprising that the areas of difficulties that were indicated by the students were consistent with the experiment results. In most cases the contributors to difficulties were poor understanding of the basic and underlying concepts, failure of establishing the appropriate linkages with prior knowledge, working memory overload due to the high rate flow of the information, abstraction and irrelevancy to daily life. In the current survey, working memory restriction was due to the holding of several frameworks at same time. The survey showed that students had great difficulty in dealing with different domains at same time and moving from one domain to another. This is a general problem that may appear as different forms like here as transformation between different co-ordinate systems.

6.2.2 Conclusion from the Units

The investigation has identified widespread difficulties that students have in visualising the basic underlying concepts in astronomy. Most of the students fail to apply the basic concepts in a real situations. They were not able to connect the concepts to the natural phenomena. For example they were not able to interpret why the lengths of days and nights is varying in different times of the year. They did not have a clear explanation for the positions of the Sun in the sky and they were not competent to predict the path of the Sun at different times of the year. The study revealed that students did not have a clear image of celestial sphere, equator and vernal equinox. The failure in grasping these concepts caused severe problems that students reported in the difficulty survey.

Most of the students realised that the style of the relativity unit was a break from common exercises that they had seen before, such as gedanken experiments, and application to relativistic and subatomic particles. Even more, some of them expected to confront with exercises in particle physics, but here the intention was to deal with more tangible implications of special relativity to make abstract contents more concrete. Students expressed that it was challenging for them to go through the unit, and look at this topic from a different perspective. Even the advanced students had difficulty in handling the space diagrams and also in particular in distinguishing between the events which are simultaneous and events which are seemed to be simultaneous.

6.3 School Experiments

The school experiments comprised of two stages. First energy unit experiments and second measuring the attitudes. Again according to the time restrictions the unit was not basically developed for school level and it was a revision from a version which was basically prepared for university purpose. In this view the unit may suffers from some shortages. However, this may not affect the overall aim of this part of the study which was enhancing conceptual change by using group learning. Collaborative learning can be regarded as an alternative approach toward cognitive conflict that may provide students with different views from the group. The experiment revealed that there is a severe difficulty in grasping the concept of energy and it was encouraging that this approach improved the meaningful learning among the students.

6.4 Limitations

There were several restrictions in accomplishing this study. The small number of participants in the survey was one of the limitations that made the results not good enough to be trusted. Even more It was not a quite right time of the year as the survey carried out in first semester and unit experiments in second semester, thus some of the students who attended the survey were not accessible anymore.

According to unexpected local holidays the special relativity students were not present and more advanced students participated in the experiments which were not the second years students who attended the difficulty survey and this was not the main intention of this study.

Due to the time restrictions of a Master degree, many basic concepts remained unexamined. For example time and reference frames are basic concepts in special relativity and there is potential for confusion in these fields that is worthy to be considered in further research.

The experiment can be repeated again in different astronomy classes in following years. It was encouraging that most of the astronomy lecturers found the units useful and they were keen to use the exercises in their class.

6.5 Further Work

The traditional approach toward learning science accompanying passive learning strategies, still is a strategy that has been adopted in most science classes. Students usually resist to change this style, as this is the method they had used to learn in their previous instruction and it seems that it had worked for them and they may have epistomoligicals beliefs to continue the tactics of memorising and rote learning. The reconstruction of traditional methods of instruction and changing the students' cognitive network can be a subject of much more research. The right time has come to put this question open to debate that what should be the strategy of teaching physics, pursuing the classical methods of teaching physics and producing scientists who are good in handling complicated multistep algorithms or physicist with basic conceptual understanding who is competent to unify the whole physics and solve the problems conceptually.

The current study was a small pilot study for a much more extensive one to be used in further research. A target is to develop on-line, self-diagnostic learning material to help students to modify their own basic conceptual understanding. The pilot has been more successful than was anticipated. The students' attitude has been positive, and that of their lecturers has shifted from interested but sceptical tolerance to enthusiasm. This would seem to justify the development of on-line material, available via the World Wide Web. Material, to be used at the students' because, can be constructed in much more sophisticated ways. Bad answers and use of hints can be used to force the students along suitable tracks, records can be kept, and the students, or the teacher, can be provided with information about progress if that seems desirable.

References

Anderson, P. W. (1993) Review of James Gleick's Genius, *Science*, 259, 22.

Ashcraft, M. H., (1994) *Human Memory and Cognition*, 2nd Edition. New York: Harper Collins.

Atkinson, R.L., Atkinson, R.C., Smith, E.E., (1993) *Introduction to Psychology*, 11th Edition, USA: Harcourt Brace Jovanovich College Publishers.

Ausubel, D.P., Novak, J., and Hanesian, H., (1978) *Educational Psychology: A Cognitive View*, New York: Holt, Rhinehart and Winston.

Ausubel, D., P. (1963). *The Psychology of Meaningful Verbal Learning*. New York: Grune & Stratton.

Ausubel, D.P., (1962) A subsumption theory of meaningful verbal learning and retention, *The Journal of General Psychology*, **66**, 213-244.

Ausubel, D.P., (1968) *Educational Psychology - a Cognitive View*, London: Holt, Rhinehart and Winston.

Baddeley, A.D, (1992) Is Working Memory Working? The Fifteenth Bartlett Lecture, *Quarterly Journal of Educational Psychology*, **44A**(1), 1-31.

Baddely, A. D. (1999) *Essentials of Human memory* ,Hove, England Psychology Press.

Baddeley, A.D., (1986) *Working Memory*, Oxford: Clarendon Press.

Baddeley, A.D., (1994) The Magic Number Seven: Still Magic After all These Years? *Psychological Review*, **101**(2), 353-356.

Bat-Sheva Eylon and Uri Ganiel (1990) Macro-Micro relationships: the missing link between electrostatics and electrodynamics in students' reasoning, *International Journal of Science Education*, **12**(1) 79-94.

Baxter, J. (1989a) Children's understanding of familiar astronomical events, *International Journal of Science Education*, 11(5) 502-513.

Baxter, J. (1989b) Children's understanding of familiar astronomical events, *International Journal of Science Education*, **23**(11), 302-313.

Bernhard, J. (2000) *Improving engineering physics teaching - learning from physics education research*, Proceedings of PTEE2000 "Physics Teaching in Engineering Education", Budapest 13 - 17.

Breitenberger, E. (1991) The mathematical knowledge of physics graduates: Primary data and conclusions, *American Journal of Physics*, **60** (4) 318-323.

Bruner, J.S. (1966) *Toward a Theory of Instruction*, Cambridge Mass.: Harvard University Press.

Carrol, W.B., and Ostile, A.D. (1996) *An Introduction To Modern Astrophysics*, Addison-Wesley Publishing Company Inc, England.

Case, R., (1974), Structures and Strictures, some functional limitations on the course of cognitive growth, *Cognitive Psychology*, **6**, 544-573.

Clement, J.J., (1998) Expert novice similarities and instruction using analogies, *International Journal of Science Education*, **20**(10) 1271-1286.

Cobern, W.W. (1996) Constructivism and non-western science education research, *International Journal of Science Education*, **18**(3), 295-310

Craik, K. (1943) *The nature of Explanation*, Cambridge University Press, London, New York.

Crawley, F. and Black, C. (1992) Casual modelling of secondary science students intentions to enrol in Physics, *Journal of Research in Science Teaching*, **29**(6), 585-599.

Dawson, C.J. (1978) Pupils Difficulties - what can the Teacher do ? *Education in Chemistry*, **15**, 120-121.

Driver, R. and Erickson, G. (1983) Theories in action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science, *Studies in Science Education*, **10**, 37-60.

Driver, R. and Oldham, V. (1986) A Constructivist Approach to Curriculum Development in Science *Studies in Science Education*, **13**, 105-122.

Driver, R. (1989) Students' conceptions and the learning of science,*International Journal of Science Education*, **11**(5) 481-490.

Duct, R.F. , Goldberg, and Niedderer, H. (1992) eds. *Research in Physics learning : Theoretical Issues and Empirical studies*, IPN: Kiel.

Dykstra, D.I. (1991) *Studying Conceptual Change: Constructing New Understandings, Research in Physics Learning: Theoretical Issues and Empirical Studies*, Proceeding of an International Workshop, 40-58.

Elby, A. (1999) Another reason that physics students learn by rote, Physics Education Research, *American Journal of Physics*, **67**(7), S52-S57.

Epstein, C.L. (2000) *Relativity Visualised*, Insight Press, San Francisco.

Finegold, M. & Gorsky, P., (1991) Students' concepts of force as applied to related physical systems: A search for consistency, *International Journal of Science Education*, **13**(1) 97-113.

Five to Fourteen (5-14) *National Guidelines (2000) Guide for Teachers and Managers*, Dundee, Learning and Teaching Scotland.

Flavell, J H. (1963) *The Developmental Psychology of Jean Piaget*, Princeton, N.J., Van Nostrand.

Furth, H.G. (1970) *Piaget for teachers*, N. J.,Prentice -Hall, Inc.

Gagné, R.M. and Briggs, L.J. (1974) *Principle of Instructional Design*, New York: Holt, Rinehart and Winston, Inc.

Gagné, R.M. (1968) Learning Hierarchies, *Educational Psychologist*, **6**, 1-9.

Gagné, R.M. (1970) *The Conditions of Learning*, 2nd Edition, New York: Holt, Rinehart and Winston.

Gagné, R.M. (1977) *The Conditions of Learning*, 3nd Edition, New York: Holt, Rinehart and Winston.

Gagné, R.M. (1985) *The Conditions of Learning and Theory of Instruction*, 4nd Edition, New York: Holt, Rinehart and Winston.

Gagné, R.M., Briggs, L., and Wager, W. (1992) *Principle of Instructional Design*, 4th ed. Fort Worth, TX: HBJ College Publishers.

Gilbert J.K. and Watts D.M. (1983) Concepts, misconceptions and alternative conceptions; Changing perspectives in science education, *Studies in Science Education*, **10**, 61-98.

Glasersfeld, E.V. (1987) *Cybernetics, Experience, and the concept of Self , The construction of Knowledge: Contributions to Conceptual Semantics*, CA: The Systems Inquiry Press.

Grant, R. M. (1978) *Group and individual problem solving at high school students*, Ph.D. Thesis, University of Oklahoma Graduate College.

Gribbin, J. and Gribbin, M. (1997) *Richard Feynman: A Life in Science*, New York: Dutton.

Halliday, D., and Resnick, R., and Walker, J., (1994) Fundamentals of Physcis ,Wiley, NewYork, 4th ed.

Harrington, R. (1999) Discovering the reasoning behind the words: An example from electrostatics, *American Journal of Physics*, Supplementary, **67**(7), S58- S59.

Henry, G. D. and King, R.C. (1994) On theory of learning and knowledge: educational implications of advances in neuroscience, *Science Education*,**78**, 223-253.

Herron, J.D. (1975) Piaget for Chemists, Explain what Good Students Cannot Understand, *Journal of Chemical Education*, **52**(3), 146-150.

Hood, G.C. (1993) Teaching about Quantum Theory, *Physics Teacher*, **31**(5) 290-293.

Howe, T.V. and Johnstone, A.H., (1971) *Reason or Memory? - The learning of Formulae and Equations*, Dundee, National Curriculum Development Centre, Bulletin No.1.

Hyde, D.M.G. (1970) *Piaget and Conceptual Development*, Ayles, Bucks.:Hazell, Watson and Viney Ltd.

Jenkins, E.W. (1978) Piaget and School Chemistry - a Critique, *Education in Chemistry*, **15**, 85-86.

Johnstone, A. H. and El-Banna, A. (1986), Capacities, demands and processes - a predictive model for science education, *Education in Chemistry*, **23(5)**, 80-84, 1986.

Johnstone, A. H. and Kellett, N. C. (1980), Learning Difficulties in School Science - Towards a Working Hypothesis, *European Journal of Science Education*, **2**(2), 175-181.

Johnstone, A. H., Watt, A., and Zaman, T.U. (1998), The students' attitude and cognition change to a physics laboratory, *Physics Education*, **33**(1) 22-29.

Johnstone, A.H. (1980), Nyholm Lecture: Chemical Education Research: Facts, Findings, and Consequences, *Chemical Society Reviews*, **9**(3), 363-380.

Johnstone, A.H. (1982) Macro and micro chemistry, *School Science Review*, **64**(227), 377-379.

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. and Al-Naeme,F.F.(1991), *International Journal of Science Education*, **13**(2) 187-192.

Johnstone, A.H. (1997) '...And some fell on good ground', *University Chemistry Education*, **1**(1) 1-36.

Johnstone, A.H. and Kellet, N.C. (1980) Learning Difficulties in Schools Science Towards a Working Hypothesis, *European Journal of Science Education*, 2(2) 175-181.

Johnstone, A.H. and Reid, N., (1979) New Science Teaching Materials, Dundee, Curriculum Development Centre, *Research Supplement Bulletin*, **15.**

Johnstone, A.H., Hogg, W.R., Ziane, M. (1993) A working memory model applied to physics problem solving, *International Journal of Science Education*, **15**(6), 663-672.

Johnstone, A.H., and Su, W.Y. (1994) Lectures - a learning experience?, *Education in Chemistry*, **31**(3) 75-79.

Johnstone, A.H., (1996) Chemistry Teaching, Science or Alchemy?, *Journal of Chemical Education*, 74 (3) 262-268.

Johnstone, A.H., Morrison, T.I. and Sharp D.W.A. (1971) Topic Difficulties in Chemistry, *Education in Chemistry*, **8**, 212.

Johnstone, A.H. (1984) New Stars for the Teachers to Steer by? *Journal of Chemical Education*, **61**(10), 847-849.

Kalman, C.S., Morris, S., Cottin, C., Gordon, R. (1999) Prnoting conceptual change using collaborative groups in quantitative gateway courses, *American Journalof Physcis. Suppl.* **67**(7), S45-S51.

Kaper, H.W., Goedhart, J.M. (2002) 'Forms of Energy', an intermediary language on the road to thermodynamics? Part I, *International Journal of Science Education*, **24**(1), 81-95.

Kellett, N. C. (1978), *Studies on the Perception of Organic Chemical Structures*, Ph.D. Thesis University of Glasgow.

Kim, E. (2001) Students do not overcome conceptual difficulties after solving 1000 traditional problems, *American Journal of Physics*, **70**(7), 759-765.

Klein, C. (1982) Children's concepts of Earth and the Sun: a cross-cultral study, *Science Education*, **65**, 95-107.

Knight, R. D. (1995) The vector knowledge of beginning physics students, *Physics Teacher*, **33**, 74-78.

Kohnstamm, G.A. (1967). *Piaget's Analysis of class Inclusion: Right or Wrong?* The Hague: Monton.

Kuhn, T. (1970) *The structure of Scientific revolutions*, 2nd edn., Chicago: Chicago University Press.

Likert,R. A. (1932) *Technique for the measurement of Attitudes*, NewYork, Colombia University Press.

Mahmoud, N.A. (1979) *An Experimental Study in Diagnostic Testing and Concept Development in Secondary School Biology*, Ph.D. Thesis, University of Glasgow.

Martinez Pena, B., Gail Quilez, M.J., (2001) The importance of images in astronomy education, *International Journal of Science Education*, **23**(11), 1125-1135.

Maskill, R., Pedrosa de Jesus, H. (1997) Pupils' questions, alternative frameworks and the design of science teaching, *International Journal of Science Education*, **19**(7), 781-799.

McDermott, L. C., Shaffer, S.P., Rosenquist, M.L. (1996) *Physics By Inquiry*, Volume 1&2, John Wiley & Sons, Inc. New York.

McDermott, L.C. and Radish, E.F. (1999) , Resource Letter, *American journal of Physics*, **67**(9), 755-767.

McDermott, L.C. (1993), Guest comment: How we teach and how students learn- A mismatch? *American Journal of Physics*, **61**(4) 295-298.

McDermott, L.C. (2002), Oersted Medal lecture: "Physucs Education Research-The key to Student Learning" *American Journal of Physics*, **69**(11) 295-298.

McNally, D.W. (1974) *Piaget, Education and Teaching*, Sussex, England, New Educational Press Ltd.

Miller, G. A., (1956) The magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information, *Psychological Review*, **63**(2), 81-97.

Murphy, P., Klages, E., Shore,L., and the staff of the Exploratorium (1997) *The Science Explorer Out and About*, Henry Holt and company, New York.

Nakhleh,M.B. and Mitchell, R.C. (1993) Concept Learning Versus Problem Solving: There is a Difference. *Journal of Chemical Education*, **70**(3), 190-192.

Neuman, J.von (1958) *The Computer and the Brain*, Yale, University Press.

Niaz, M., 1987, "Relationship between M-Space of students and M-demand of Different Items of General Chemistry and its Interpretation based upon the Neo-Piagetian Theory of Pascual-Leone", *Journal of Chemical Education*, **64**(6), 502-505.

Niedderer, H. and Schecker, H. (1991) Towards an explicit description of cognitive systems for research in physics learning, Theoretical Issues and Empirical Studies, *Proceeding of an International workshop*, University of Bremen, eds.; Duit,R., Goldberg,F. and Neidderer, H., Keil, Inst, Fuer dic, Paedagogik der Naturwiss,74-87.

Novak. J. (1978) An Alternative to Piagetian Psychology for Science and Mathematics Education, *Studies in Science Education*, **5**, 1-30.

Osborne, J. R. and Beverley F. Bell, (1983) Science teaching and children's views of the world, *International Journal of Science Education*, **5**(1) 1-14.

Osborne, R.J. and Wittrock, M.C. (1983) Learning Science ; a generative process, *Science Education*, **67**(4), 489-508.

Osborne,J., and Collins,S., (2000) Pupils' and parents' views of the school science curriculum, *School Science Review*, **82**(298), 23-31.

Osgood, C.E., Suci, C.J., and Tannenbaum, P.H., (1957) The Measurement of Meaning, Urbana Ill, University of Illinois Press.

Panse, S., Ramada, J., Calmer, A. (1994), Alternative conceptions in Galilean relativity: frames of reference, *International Journal of Science Education*, **16**(1), 63-82.

Pascaual-Leone, J., 1974, A mathematical model for the transition rule in Paiget's developmental stages, *Acta Psychologica*, **32**, 302-345.

Piaget, J. (1961) The Genetic Approach to Psychology of Thought, *Journal of Educational Psychology*, **52**(6), 275-281.

Piaget, J. (1964) Development and learning, *Journal of Research in Science Teaching*, **2**, 176-186.

Piaget, J., and Inhelder, B. (1969), T*he Psychology of The Child*, New York: Basic Books.

Radish, E.F. (1997), *Student misconceptions on classical issues at the boundary of quantum mechanics, invited talk*, APS/AAPT meeting, Washington, DC.

Redish, E.F. and Ridgen, J.S. (1997) eds. *The changing role of physics departments in modern university.* AIP Conference Proceedings 399, American Institute of Physics: Woodbury.

Ratcliffe,M., (1997) Pupil decision making about socio-scientific issues within the science curriculum, *International Journal of Science Education*, **19**(2) 167-182.

Reid, N. (1977) *From Market Place to Molecule.* This teaching unit was first published by the Scottish Council for Educational Technology under the title 'Take Your Choice' and was aimed at school pupils. Later versions for both school and university students were produced in 1997, with the new title 'From Market Place to Molecule'.

Reid, N. (1978) *Attitude Development through a Science Curriculum*, Ph.D. Thesis, University of Glasgow.

Reid, N. (1980) Simulation Techniques in Secondary Education: Affective Outcomes, Simulation and Games, *SAGE Publications,* **11**(1), 107-120.

Reid, N. (1999) Bringing Work Experience to Undergraduates, *Education in Chemistry,* **36**(1), 23-24.

Reid, N., (2003) *Getting Started in Pedagogical Research in the Physical Sciences*, Learning and teaching Support Network, Hull, pages 51-52.

Reid, N. and Skryabina, E., (2002a) Attitudes Towards Physics, *Research in Science and Technological Education*, 2002, **20**(1), 67-81.

Reid, N. and Skryabina, E., (2002b) Gender and Physics, 2002, *International Journal of Science Education*, **25**(4), 509-536

Reid, N., and Yang, M.Y. (2002) Open-ended Problem Solving in School Chemistry: A Preliminary Investigation, *International Journal of Science Education*, **24**(12), 1313-1332.

Scherr, E., Staffer, P. and Vacuous, S. (2001) Student understanding of time in special relativity: Simultaneity and reference frames, *American Journal of Physics.* Supple. **69**(7), S24-S34.

Scherr, E., Staffer, P. and Vacuous, S. (2002), The Challenge of changing deeply held student beliefs about the relativity of simultaneity, *American Journal of Physics*, **70**(12), 1238-1248.

Schoenfeld, A. (1989) When good teaching leads to bad results: The disasters of well taught mathematics classes, *Educational Psychology*, **23**, 145-166.

Scott, P.H., Asoko, H.M., and Driver, R.H. (1991) *Teaching for conceptual change: A review of strategies*, Research in Physics Learning: Theoretical Issues and Empirical Studies, Proceeding of an International workshop,310-328.

Searlemann,A. and Herrman, D. (1994) *Memory from a Broader Perspective*, New York: McGraw- Hill.

Shayer, M. and Adey, P. (2002) *Learning Intelligence: Cognitive Acceleration across the curriculum from*

5 to 15 years, Buckingham: Philadelphia, PA., Open University Press.
Sirhan, G., (2000) *A Study of the Effects of Pre-learning on First Year University Chemistry Students*, PhD Thesis, university of Glasgow.

Sirhan, G., and Reid, N. (2002) An Approach in Supporting University Chemistry Teaching, *Chemistry Education: Research and Practice in Europe* (CERAPIE), **3**, 65-75.

Sirhan, G., Gray, C., Johnstone, A.H., and Reid, N., (1999) Preparing the mind of learner University *University Chemistry Education*, **3**(2),43-46.

Sirhan, G., and Reid, N. (2001) Preparing the mind of the learner- Part 2, *University Chemistry Education*, **5**, 52-58.

Smit J.J.A. & Finegold M. (1995). Models in physics : perceptions held by final prospective physical science teachers studying at South African Universites, *Int.Journal of Science.Education*,**17**(5), 621-634

Smit, J.J.A. (2001) Models, Mental Images and Language in Scientific Thinking, *Developing Formal Thinking in Physics*, First International Girep Seminar 2001 Udine, Italy.

Smart, W.M., Green, R.B. (1997) *Textbook on Spherical Astronomy*, Cambridge University Press.

Solomon, J. (1992) The classroom discussion of science-based social issues presented on television: knowledge, attitudes and values, *International Journal of Science Education*, **14**(4), 431-444.

Solomon, J. (1983) Learning about energy: How pupils think in two domains, *European Journal of Science Education*, **5**(1), 49-59.

Solomon, J. (1990) The discussion of social issues in the science classroom, *Studies in Science Education*, **18**, 105-126.

Soulsby, D. (1975) Gagné's Hierarchical Model of Learning- Some Conceptual Difficulties, *Journal of Curriculum Studies*, **7**(2), 122-132.

Sperling, G. (1960) The information available in brief visual presentations, *Psychological Monographs*, **74**(11).

Strike, K. and Poser, G. (1985) *A conceptual change view of learning and understanding*. In L. West and A.Pines (eds) Cognitive Structure and Conceptual Change (Orlando, FL: Academic Press), 211-232.

Taylor, E. F., Wheeler, J.A. (1998) *Space Time Physics*, W.H. Freeman and Company, New York.

Thumper, R. (2001) A cross-age study of junior high school students' conceptions of basic astronomy concepts, *International Journal of Science Education*, **23**(11) 1111-1123.

Trabasso, T., Foellinger, D.B., (1978), Information Processing Capacity in Children: A Test of Pascual-Leone's Model, *Journal of Experimental Child Psychology*, **26**, 1-17 ,2nd ed. New York: Holt, Rinehart and Winston.

Vosniadou, S., and Ioannides, C., (1998) From conceptual development to science education: a psychological point of view, *International Journal of Science Education*, **20**(10), 1213-1230.

Vygotsky, L. S. (1978) *Mind in society: The Development of Higher Psychological Process*, Cambridge, MA: Harvard, University Press.

Watt, G., (2002) Renewing Energy, One of a set of Interactive units (Colour and Roadsigns, Renewing Energy, Mobile Phones, Fibre Optics) produced in the university of Glasgow and available online, free, from: http://www.physsci.ltsn.ac.uk/AB/AB-html/AB-html.html.

White,R. (1988) *learning Science*, Oxford, Basil Blackwell.

Wilson, J. (1997) ed. Conference on the Introductory Physics Course, Wiley: New York.

Zapiti, Stalo, (1999) *Difficulties in Physics*, MSc Dissertation, University of Glasgow.

Zemansky, M.W., Sears, F.W., and Young, H.D., (1984) *University Physcis*, Adison-Wesley, Reading, MA, 1984,6th ed.

Astronomy 1X - Difficulties Survey

Centre for Science Education, Faculty of Education

This survey is designed to reveal the difficulties in this course.
Your participation will help us to improve learning.

Easy	***I understood it first time***
Moderate	***I found it difficult but I understand it now***
Difficult	***I still do not understand it***

If you wish you may write comments about difficulties in the space provided.

Please tick a box to show how difficult you find it to visualize or understand the following three dimensional models or physical concepts.

	easy	*moderate*	*difficult*	*If difficult, please say why*
Terrestrial latitude and longitude	☐	☐	☐	....
Great circle distance	☐	☐	☐	....
Retrograde motion of planets	☐	☐	☐	....
Lunar phase	☐	☐	☐	....
Inferior and superior planets (inferior conjunction)	☐	☐	☐	....
Greatest eastern and western elongation	☐	☐	☐	....
Kepler's law	☐	☐	☐	....
Alt-azimuth coordinate system	☐	☐	☐	....
Practical problems with altitude- azimuth coordinates	☐	☐	☐	....
The equatorial coordinate system	☐	☐	☐	....
Transformations between different coordinate systems	☐	☐	☐	....
Synodic and sidereal period	☐	☐	☐	....
Diurnal motion	☐	☐	☐	....
Seasonal change of constellations	☐	☐	☐	....
Circumpolar stars	☐	☐	☐	....
The tilt angle and the length of daylight	☐	☐	☐	....
Equinox and Solstice	☐	☐	☐	....
Mean sun	☐	☐	☐	....
Spherical triangles	☐	☐	☐	....
The Equation of time	☐	☐	☐	....
Solar time and Sidereal time	☐	☐	☐	....
Local and Greenwich sidereal time	☐	☐	☐	....
Ecliptic latitudes and longitude	☐	☐	☐	....
Mean solar times and different longitudes	☐	☐	☐	....
The difference between noon intervals	☐	☐	☐	....

Any other comments about your course

Thank you for Your Help

Astronomy 2 Relativity and Gravitation

Centre for Science Education, Faculty of Education

This survey is designed to reveal the difficulties in this course.
Your participation will help us to improve learning.

Easy	***I understood it first time***
Moderate	***I found it difficult but I understand it now***
Difficult	***I still do not understand it***

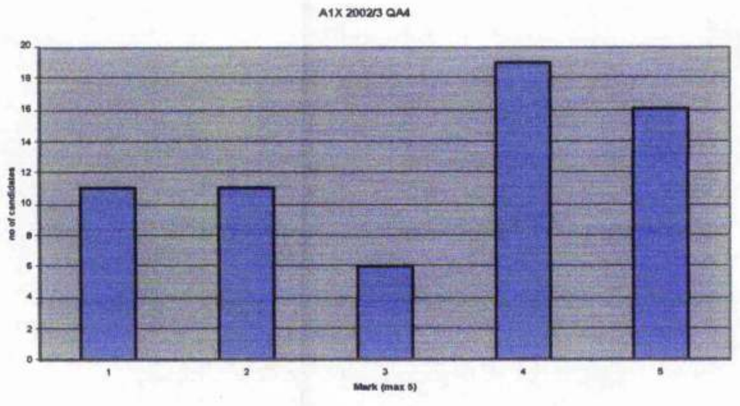
If you wish you may write comments about difficulties in the space provided.

Please tick a box to show how difficult you find it to visualize or understand the following three dimensional models or physical concepts.

	easy	*moderate*	*difficult*	*If difficult, please say why*
Inertial frames and Galilean transformation equations	☐	☐	☐	....
How easy is it for you to accept the principle of relativity and constancy of the speed of light?	☐	☐	☐	....
Lorentz transformations..	☐	☐	☐	....
Time dilation and length contraction................	☐	☐	☐	....
How difficult do visualize relativistic objects?...	☐	☐	☐	....
Velocity transformations of inertial frames..	☐	☐	☐	....
The application of transformation formula in relevant problems and shift between two frames?	☐	☐	☐	....
Relativistic Doppler effect (Longtudinal and transverse)..............................	☐	☐	☐	....
Red shift and blue shift..	☐	☐	☐	....
Relativistic momentum and energy....................	☐	☐	☐	....
Linear accelerated frames (free-fall)....................	☐	☐	☐	....
Connection between free-fall and inertial frames..	☐	☐	☐	....
Concepts of inertial and gravitational mass (Weak equivalence)	☐	☐	☐	....
Gravitational Doppler shift.................................	☐	☐	☐	....
Curved space-time...	☐	☐	☐	....
Geodesics...	☐	☐	☐	....
Relativity of sumaltaneity..................................	☐	☐	☐	....

Any other comments about your course

Thank You for Your Help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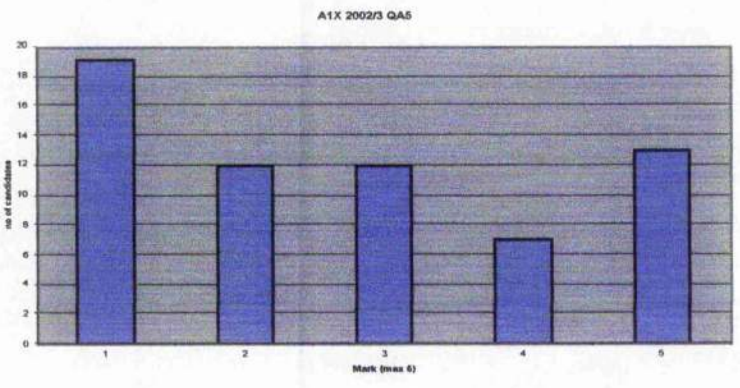
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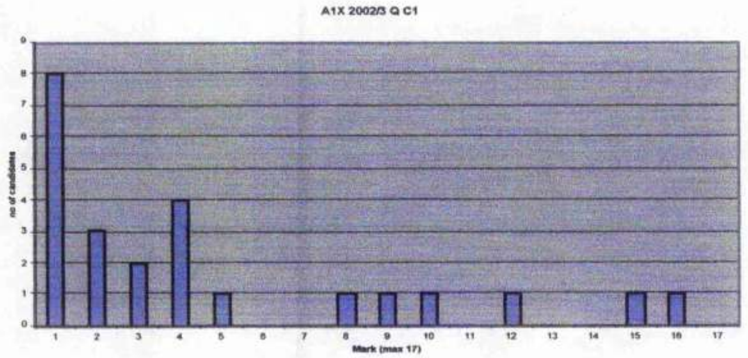
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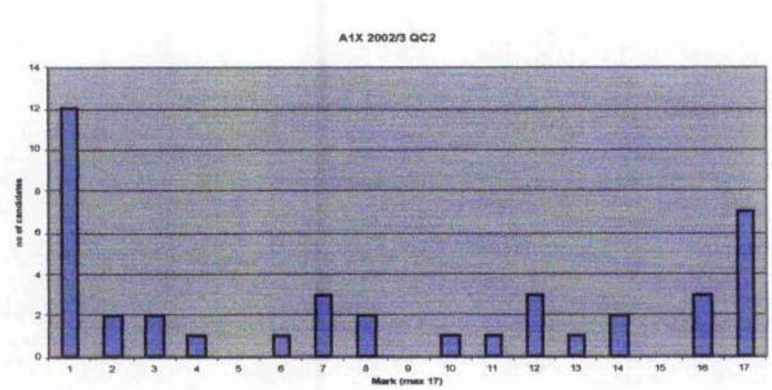
Mark (max 17)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no of candidates
Mark (max 17)

Positional Astronomy

Student Performance

Task	Number and percentage of students who gave correct answers out of N=27	Number and percentage of students who have some ideas out of N=27	Number and percentage of students who attempt to do the task but gave wrong answers out of N=27
1a	16 (59%)	3 (1%)	11 (40%)
1b	22 (82%)	3 (11%)	2 (7%)
1c	19 (70%)	0 (0%)	7 (25%)
2a	7 (25%)	9 (3%)	5 (19%)
2b	4 (15%)	4 (15%)	9 (33%)
2c	22 (19%)	1 (3%)	3 (11%)
3a	3 (11%)	12 (44%)	8 (30%)
3b	2 (7%)	2 (7%)	5 (19%)
4a	2 (7%)	6 (22%)	4 (15%)
5a	11 (40%)	0 (0%)	4 (15%)
5b	11 (40%)	1 (3%)	3 (11%)
5c	3 (11%)	4 (15%)	2 (7%)
6a	2 (7%)	4 (15%)	6 (22%)
6b	1 (3%)	0 (0%)	11 (40%)
6c	0 (0%)	8 (30%)	4 (15%)
6d	2 (7%)	0 (0%)	8 (30%)
6e	0 (0%)	1 (3%)	6 (22%)
7a	0 (0%)	2 (7%)	1 (3%)
7b	1 (3%)	0 (0%)	2 (7%)
8a	0 (0%)	1 (3%)	4 (15%)
8b	1 (3%)	2 (7%)	1 (3%)
9a	0 (0%)	0 (0%)	0 (0%)
9b	1 (3%)	0 (0%)	0 (0%)

Table 2

Positional Astronomy

Hints Offered to Students

Hint Number	The number of students used hints (out of N=27)
Hint 1	5
Hint 2	2
Hint 3	2
Hint 4	3
Hint 5	4
Hint 6	5
Hint 7	6
Hint 8	3
Hint 9	1

Table 2

Positional Astronomy

**We should like to know your reaction to the material you have just completed.
Please answer the following questions as honestly as you can.
This will help future planning.**

(1) Tick ***one box for each line*** to show your opinion: N = 12

Positional Astronomy is

Straightforward	☐	☐	☐	☐	☐	☐	Complicated
Boring	☐	☐	☐	☐	☐	☐	Enjoyable
Too mathematical	☐	☐	☐	☐	☐	☐	Not too mathematical
Experimental	☐	☐	☐	☐	☐	☐	Theoretical
Hard to visualise	☐	☐	☐	☐	☐	☐	Easy to visualise
Clear	☐	☐	☐	☐	☐	☐	Confusing

(2) Tick the box which ***best reflects your experience*** of positional astronomy:

	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
I found the subject full of complicated language	☐	☐	☐	☐	☐
There was too much information to absorb	☐	☐	☐	☐	☐
I found it difficult visualise what was happening	☐	☐	☐	☐	☐
The idea of the vernal equinox is difficult to visualise	☐	☐	☐	☐	☐
It is difficult to understand celestial coordinates	☐	☐	☐	☐	☐
I find thinking in three dimensions very hard	☐	☐	☐	☐	☐

(3) Thinking about ***the material you have just completed***, tick the box which best reflects your experience;

	Strongly agree	Agree	Disagree	Strongly disagree
The material helped me to spot the areas where I had difficulty	☐	☐	☐	☐
The hints which were offered were useful	☐	☐	☐	☐
I can 'see' some of the ideas behind better now	☐	☐	☐	☐
I did not have enough time to complete it properly	☐	☐	☐	☐
I liked the style of the questions	☐	☐	☐	☐
I understand things better now	☐	☐	☐	☐
It simplified the ideas for me	☐	☐	☐	☐

(4) **The most difficult aspect of positional astronomy, in my opinion is**

(5) **The most helpful part of the material I have just completed was**

(6) **The plan is to extend the material and place it on the web so that future students can seek help when they want. Please suggest any ideas to make this as helpful as possible**

Thank You

Special Relativity

We should like to know your reaction to the material you have just completed.
Please answer the following questions as honestly as you can.
This will help future planning.

(1) Tick ***one box for each line*** to show your opinion:

Relativity is

Straightforward	☐	☐	☐	☐	☐	☐	Complicated
Boring	☐	☐	☐	☐	☐	☐	Enjoyable
Too mathematical	☐	☐	☐	☐	☐	☐	Not too mathematical
Hard to visualise	☐	☐	☐	☐	☐	☐	Easy to visualise
Clear	☐	☐	☐	☐	☐	☐	Confusing

(2) Tick the box which ***best reflects your experience*** of special relativity:

	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
I found the subject full of complicated language	☐	☐	☐	☐	☐
There was too much information to absorb	☐	☐	☐	☐	☐
I found it difficult visualise what was happening	☐	☐	☐	☐	☐
I found the concepts strange	☐	☐	☐	☐	☐
It is too far from reality	☐	☐	☐	☐	☐

(3) Thinking about ***the material you have just completed***, tick the box which best reflects your experience:

	Strongly agree	Agree	Disagree	Strongly disagree
The material helped me to spot the areas where I had difficulty	☐	☐	☐	☐
I can 'see' some of the ideas behind better now	☐	☐	☐	☐
I need more time to work on it properly	☐	☐	☐	☐
I liked the style of the questions	☐	☐	☐	☐
I understand things better now	☐	☐	☐	☐
It simplified the ideas for me.	☐	☐	☐	☐

(4) The most difficult aspect of special relativity, in my opinion is

(5) The most helpful part of the material I have just completed

(6) The plan is to extend the material and place it on the web so that future students can seek help when they want. Please suggest any ideas to make this as helpful as possible.

Thank You

Centre for Science Education, University of Glasgow

All Data shown as % N=27

Centre for Science Education

As you are aware we have produced some trial material related to ...Special Relativity...and students have worked through it. In addition to their answers to the questions they have made comments on the nature, style, difficulty, relevance, and usefulness of the material. It is important that we also seek the opinions of their lectures.

By way of background, we are trying to provide students with the means to assess their own *understanding* of the important ideas. There are pedagogic theories, or models, of what 'undestanding' means, and there is an extensive literature on the failure of traditional courses in physics, at all levels, from primary school to graduate school, to generate real conceptual, understanding. Our project is not aimed at replacing traditional courses, which have many good features, but at supplementing them with self-administrated challenges which are independent of paticular courses and lecturers, and which may reveal to the student that more thought is needed.

In connection with the material related to your course, how do you rate the questions asked of the students:

Too easy	☐	☐	☐	☑	☐	☐	Too difficult
The style was annoying	☐	☐	☐	☐	☐	☑	The style was ok
The questions were relevant	☑	☐	☐	☐	☐	☐	The questions were irrelevant
The exercise was a useful one	☑	☐	☐	☐	☐	☐	The exercise was useless

Do you have any additional comments?

In addition to the exercices of the relativity of space and time, some exercices about the relativity of energy and momentum might be useful. The questions about the shape of objects were very useful. Some more of these (e.g. more tricky shapes) might be good.

Thank you for your time

Centre for Science Education

As you are aware we have produced some trial material related to ...Positional Astronomy... and students have worked through it. In addition to their answers to the questions they have made comments on the nature, style, difficulty, relevance, and usefulness of the material. It is important that we also seek the opinions of their lectures.

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In connection with the material related to your course, how do you rate the questions asked of the students:

Too easy	☐	☐	☐	☑	☐	☐	Too difficult
The style was annoying	☐	☐	☐	☐	☑	☐	The style was ok
The questions were relevant	☑	☐	☐	☐	☐	☐	The questions were irrelevant
The exercise was a useful one	☐	☑	☐	☐	☐	☐	The exercise was useless

Do you have any additional comments?

See accompanying notes

At 1st year level, what would be also very good would be to reinforce the ideas in the questionnaire with a practical "lab" experiment - i.e. an outdoor activity where the students measure positional angles for themselves.

Thank you for your time

Centre for Science Education

As you are aware we have produced some trial material related to ..*Special Relativity*..and students have worked through it. In addition to their answers to the questions they have made comments on the nature, style, difficulty, relevance, and usefulness of the material. It is important that we also seek the opinions of their lectures.

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The style was annoying	☐	☐	☐	☐	☑	☐	The style was ok
The questions were relevant	☑	☐	☐	☐	☐	☐	The questions were irrelevant
The exercise was a useful one	☑	☐	☐	☐	☐	☐	The exercise was useless

Do you have any additional comments? (note, I did not teach this course, but am commenting based on what I have seen from my student group). I liked the questions regarding frames + simultaneity particularly. I Do not like question 6b; belief has no place in science – this requires only verification!

Thank you for your time

Centre for Science Education

As you are aware we have produced some trial material related to Positional Astronomy and students have worked through it. In addition to their answers to the questions they have made comments on the nature, style, difficulty, relevance, and usefulness of the material. It is important that we also seek the opinions of their lectures.

By way of background, we are trying to provide students with the means to assess their own *understanding* of the important ideas. There are pedagogic theories, or models, of what 'undestanding' means, and there is an extensive literature on the failure of traditional courses in physics, at all levels, from primary school to graduate school, to generate real conceptual, understanding. Our project is not aimed at replacing traditional courses, which have many good features, but at supplementing them with self-administrated challenges which are independent of paticular courses and lecturers, and which may reveal to the student that more thought is needed.

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The style was annoying	☐	☐	☐	☐	☑	☑	The style was ok
The questions were relevant	☐	☑	☐	☐	☐	☐	The questions were irrelevant
The exercise was a useful one	☑	☐	☐	☐	☐	☐	The exercise was useless

Do you have any additional comments? (NB, I am not teaching this course, but answering from ~~thee~~ a position of familiarity with the course content) Extremely useful for a fundamental understanding of the reasons for changes in the night sky, reference points, timekeeping etc. Forces students to think, without equations. But, requires a fairly high degree of visualisation skills, which not everyone has (including me!)

Thank you for your time

Centre for Science Education

As you are aware we have produced some trial material related to POSITIONAL ASTRONOMY and students have worked through it. In addition to their answers to the questions they have made comments on the nature, style, difficulty, relevance, and usefulness of the material. It is important that we also seek the opinions of their lectures.

By way of background, we are trying to provide students with the means to assess their own *understanding* of the important ideas. There are pedagogic theories, or models, of what 'undestanding' means, and there is an extensive literature on the failure of traditional courses in physics, at all levels, from primary school to graduate school, to generate real conceptual, understanding. Our project is not aimed at replacing traditional courses, which have many good features, but at supplementing them with self-administrated challenges which are independent of paticular courses and lecturers, and which may reveal to the student that more thought is needed.

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The questions were relevant	☑	☐	☐	☐	☐	☐	The questions were irrelevant
The exercise was a useful one	☑	☐	☐	☐	☐	☐	The exercise was useless

Do you have any additional comments?

THIS WAS A VERY USEFUL EXERCISE - THE FEEDBACK FROM THE STUDENT QUESTIONNAIRE WAS ACTUALLY QUITE ILLUMINATING W RESPECT OF HIGHLIGHTING CONCEPTUAL DIFFICULTIES WITH THE COURSE, AND CLARIFYING THOSE PARTS WHICH WERE WELL UNDERSTOOD. THE 'DESERT ISLAND ASTRONOMY' EXERCISE WAS BOTH USEFUL + ENTERTAINING! IT CERTAINLY PROVOKED THE STUDENTS INTO EXAMINING MORE CLOSELY EXACTLY WHAT THEY UNDERSTOOD! THE EXERCISE WILL PROVE MORE USEFUL NEXT SESSION WHEN IT CAN BE GIVEN OUT DURING THE POSITIONAL ASTRONOMY TEACHING.

Thank you for your time

Centre for Science Education

As you are aware we have produced some trial material related to RELATIVITY and students have worked through it. In addition to their answers to the questions they have made comments on the nature, style, difficulty, relevance, and usefulness of the material. It is important that we also seek the opinions of their lectures.

By way of background, we are trying to provide students with the means to assess their own *understanding* of the important ideas. There are pedagogic theories, or models, of what 'undestanding' means, and there is an extensive literature on the failure of traditional courses in physics, at all levels, from primary school to graduate school, to generate real conceptual, understanding. Our project is not aimed at replacing traditional courses, which have many good features, but at supplementing them with self-administrated challenges which are independent of paticular courses and lecturers, and which may reveal to the student that more thought is needed.

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Too easy	☐	☐	☐	☑	☐	☐	Too difficult
The style was annoying	☐	☐	☐	☐	☐	☑	The style was ok
The questions were relevant	☑	☐	☐	☐	☐	☐	The questions were irrelevant
The exercise was a useful one	☐	☑	☐	☐	☐	☐	The exercise was useless

Do you have any additional comments?

RELATIVITY POSES MANY CONCEPTUAL DIFFICULTIES FOR STUDENTS (+ STAFF!)
THIS EXERCISE IS USEFUL IN THAT IT EXPOSES THE CORE ISSUES WITHOUT
BECOMING TOO OBSESSED WITH NUMERICAL/FORMULAIC EXERCISES + PROBLEMS
I LOOK FORWARD TO USING IT ON A PROPER CROSS-SECTION OF THE CLASS NEXT YEAR

Thank you for your time

Renewing Energy

Tutor's Guide

This teaching resource is one of a set of units, modified in an attempt to make Physics accessible. The main aim of this unit is not to teach about energy but to expose pupils to a current issue facing governments and electrical energy producers. This will lead to a greater appreciation of the interaction of political imperatives, commercial forces, moral considerations and conflicting interests in a real-life situation.

At the end of the package, the pupil is expected to:

(a) Be more aware of the nature, technology and costs of the main processes for electricity generation.
(b) Appreciate in a more sophisticated way some of the important issues in determining the ways by which electricity should be generated in a way acceptable in today's society.
(c) Be more able to appreciate that there may be several valid but conflicting approaches in searching for solutions to problems involving physics.
(d) Understand that commercial decisions have to take account of physics realities *and* social acceptability.
(e) Accept that discussion and compromise are part of political and commercial decision making.

By experiencing different views of the same issue, pupils are encouraged to recognise the many facets of real-life decision taking and to accept that decisions often have to be made on the basis of incomplete information. Pupils will also have opportunities to assess data presented in several forms, to weigh arguments, to contribute to a group discussion, to present arguments based on gathered evidence and to listen to the arguments proposed by others. They should begin to see the place of such skills in the context of their education in Physics.

How the Unit Operates

For pupils to gain the maximum benefit from this unit, the following procedures should be followed carefully. It is important that the pupils are allowed to interact in groups with the materials. The role of the teacher becomes more that of **manager** of learning. Following an introduction, the unit is planned as a role play exercise.

(1) Introduction Paper: Give each pupil a copy (white) and allow about 3 minutes reading time.

(2) Form groups each of which has three pupils. An occasional four is possible.
Give each pupil a copy of the paper entitled Overview (yellow).
Allow about 20 minutes to read and for the group to complete the table.
The am of this part is to encourage the pupils to share some of the key issues relating to efficiency from practical considerations or from technological limitations.

(3) In each group of three,

To pupil 1:	Issue the pink briefing paper:	"Fossil, solar"
To pupil 2:	Issue the green briefing paper:	"Hydro, wave"
To pupil 3:	Issue the blue briefing paper:	"Tidal, Nuclear, wind"

Allow about 15-20 minutes for reading and some initial thinking. Encourage the three pupils to talk to each other, discussing how they might assess the potential sources of energy

(4) Give each group a copy of sheet entitled Your Group Task (white) and allow the three pupils to report to each other (each is allowed 3 minutes) and then to discuss the issues leading them to the development of strategy. Issue a blank overlay and pen after 20 minutes so that they can prepare their presentation. Overall, allow about 20-30 minutes.

(5) If there are up to four groups of three pupils, allow each group to make a presentation, with the teacher acting as the Secretary of State. Where there are larger numbers, a limited number of presentations can be made or presentations can be written.

Allow as long as necessary de-briefing.

The total time required for the unit is likely to be around 1 to 1.5 hours

De-briefing

It is important to hold an open discussion at the end. This should be led by the teacher and may involve many groups of three. It is useful to use this time to compare the conclusions of several groups and to highlight the key issues raised by the unit. These may relate directly to the Physics behind the unit or may be of a more social nature. It is also an opportunity to relate the unit to coursework. In addition, there should be an opportunity for pupils to raise any issues that have emerged.

Background Information for the Teacher

One logical way to tackle this unit is for pupils to list the various sources of energy and assess each under headings like: capital costs for MW, running costs for kWh, potential for development (perhaps in GW capacity), carbon dioxide emissions criteria under the Renewable Obligations criteria, social acceptability and so on. Do not tell them this unless a group is hopelessly stuck but allow them to develop their own strategy.

It is likely that they will come up with tidal, solar, wave, and wind as options worth exploration, with the costs of solar and wind making them the more attractive. They will need about 35 TWh to come from such sources per year, requiring a generating capacity of at least 7GW, considerably more if wind is used.

This unit was originally written by Graham Watt and edited by Norman Reid under funding from the Learning and Teaching Support Network (Copyright © 2002). It was later edited in this version for school pupils.

Introduction

Energy in Britain

You are a scientist working for the Department of Trade and Industry. The year is 2004. The Government is required to provide the European Commission with its strategies to reduce carbon dioxide emissions by 10% over the next 5 years and, with an election next year, it must do this without losing popularity. The strategy must also fulfil Britain's undertaking in the Renewables Obligation (RO) to have 10% of all electricity coming from renewable sources by 2010. Energy is a controversial subject as the industry accounts for 4% each of the Gross Domestic Product (GDP) and industrial employment in the UK. Overall, the industry represents 28% of total industrial investment.

Since it is the generating companies who will ultimately have to implement your them, your decisions must be taken with an eye to commercial necessities as well as environmental considerations.

The situation is all the more sensitive because the opposition parties are gaining strength in the wake of recent troubles in the Government. It is essential to make the right decision and be seen to be making it quickly. To put the question in context, the UK consumption of electricity was 330 x 10^9 kWh in 2002 and is growing steadily at a rate of approximately 1.5% per annum. The breakdown is shown in the table 1.

The current total of installed generating capacity is 65 GigaWatts (= 65 x 10^6 kW), and the anticipated investment schedule from industry is £8 million per year across all the energy industries. Approximately half of this will go directly into oil and gas extraction. The Government has allocated a total of £260 million to help develop the UK's renewable energy resources.

Table 1
Electricity available by fuel type (%)

FUEL	%
coal	28
oil	1.5
gas	38.5
nuclear	24.5
hydro	1
other fuels	2.5
net imports	4
Total	100

The major possible types of electricity generation have been broken up into three briefing packs. Working in a team of three, each of you should take one of the packs and review the operational, environmental and economic factors associated with the techniques. Prepare a short briefing for your colleagues, and then, in your team of three, develop a proposal for energy strategy for the next five years. Remember that you need to satisfy the projected demand for electricity while meeting the targets on the reduction of environmental impact. There will be questions in the House of Commons tomorrow. Therefore, it is essential that you work quickly and produce a viable strategy

Read the Overview which your teacher will give to you. This covers the general terms of the Renewables Obligation, the thermodynamics of electricity generation, and some fuel processing techniques.

Overview

The Renewables Obligation

Renewable energy can be defined either as 'energy that occurs naturally and repeatedly in the environment' or which comes from sources other than fossil or nuclear fuel. The Renewables Obligation (RO) was a Parliamentary Order which came into effect in 2001, compelling all electricity suppliers to source a fraction of their power from renewable sources, with a target of 10% by 2010. The penalties for falling short are severe: not only a fine of £30 per MWh (1 MegaWatthour = 10^3kWh), but also seeing that money divided among your competitors who achieved their targets. The major renewable energy sources which are included in the UK renewables obligation (RO) include:

wind power, whether on-shore or off-shore
wave power
hydro-electricity
geothermal power
photovoltaic (solar) power

Hydro-electricity is a complicated matter, as it cannot be counted as renewable energy for the purpose of the RO if it is used as pumped storage but only if it is extracting 'raw' power from the water flow. All older stations (commissioned before the RO came into force) of declared net capacity over 20MegaWatts are excluded, but smaller stations are eligible, regardless of their age. Of course, hydro is still a valuable source of power when looking to reduce emissions.

A Question of Efficiency

It is possible to show that the maximum theoretical efficiency that can be achieved in a device which converts heat energy into movement energy (a heat engine) is equal to the temperature drop from input to output divided by the input temperature, measured on the Kelvin scale of absolute temperature:

$$\text{maximum efficiency} = (T_1 - T_2) / T_1.$$

For example, if steam is supplied to a steam turbine at 550°C and cooled to 27°C, then its temperature has fallen from 823 K to 300 K, and the maximum efficiency is (823-300)/823 = 63%. Real turbines fall short of this ideal, usually achieving around 70% of the maximum, or about 40% overall in this example. This is typical for a steam turbine, such as might be used in a thermal or nuclear power station. The boiler and generator losses will bring this down to around 90%, or 36% efficiency overall. The heat energy not converted to mechanical energy warms the surroundings.

Gas-fired power stations can do rather better, by using *combined-cycle gas turbines* (CCGTs). In these systems, gas is burned at a very high temperature in a gas turbine (like an aircraft engine) which can produce shaft power to drive a generator directly, before the hot waste gases are used to provide steam for a conventional steam turbine, which drives a second generator. In this way, a CCGT can achieve an overall efficiency around 50%.

Because of the very high temperatures used, CCGTs require the source gas to be very clean, to avoid corrosion of the turbine blades. At the present time, only natural gas is readily available at the required level of purity, but it is hoped that the terms of the Renewables Obligation will encourage research into methods of producing acceptably pure gas from other sources.

You will be working in a group of three.

In the table below, there are several potential energy sources.

Working together as a group, try to complete the table to show the potential sources of inefficiency in converting each to usable electrical energy. Where possible, try to use numbers and base your conclusions on physics. Consider possible energy as well as practical considerations to draw your conclusions.

The aim is that you should gain a clear overview of the idea of efficiency in considering energy transformation so that you can explain to someone not trained in physics why inefficiency is inevitable.

Energy Sources	Factors Affecting Efficiency
Fossil Fuels (gas, coal, oil)	Maximum Efficiency determined by: $(T_1 - T_2 / T_1$
Tidal Energy (from tidal movement)	
Solar Energy (thermal)	
Solar Energy (photovoltaic)	
Nuclear (Uranium or Plutonium)	
Hydro (using turbines)	
Wave (Oscillation)	
Wind (wind movement)	

Briefing Paper 1

Your Task

(1) Read this individual briefing pack which discusses the potential of some sources of energy. Pay particular attention to the points raised in the Overview Paper.

(2) On your own, prepare a short (3 minutes) presentation to your group of three on the viability of the resources you have studied. What advantages and disadvantages does each have in operational terms? How do they fit in to the current political climate? You will need to use numbers wherever possible in your approach so that comparisons can be made with other sources.

(3) The aim of your presentation is make the information known to your colleagues as clearly as possible so that, together, you can assess the relative potential of all energy sources. This is not a competitive effort. You are working as a team.

(4) After you have all given your presentations, discuss, as a team of three, which technologies seem to be most promising in terms of the information you have been given. You will need to consider what proportion of electricity you would hope to obtain from the different sources, and what level of investment is entailed. Your task is to offer advice to government, based on clear evidence, advice which is accessible to those with limited scientific training.

Fossil fuels

Fossil fuels used in the UK for electricity generation primarily means gas and coal. They operate on the very simple principle of a thermal power station, burning fuel to raise steam which drives a turbine. Most of the new facilities being built are now combined-cycle gas turbine power stations (CCGTs) which improve efficiency by extracting power directly from the burning gases in addition to raising steam.

Fossil fuels have the great advantage that they are easy to use, burn efficiently with the new technologies, and are very responsive to surges in demand. The fuels themselves are fairly cheap, although they have the disadvantage that the prices vary with the oil market, and supplies can be affected by international affairs plus, of course, the production of greenhouse gases. On average, 1 GWh (10^6kWh) of electricity releases 160 tonnes of carbon dioxide into the atmosphere. Burning coal, in particular, also produces oxides of sulphur, which are another contribution to the greenhouse effect.

Typical construction costs are in the region of £0.8 million per MW for a coal or oil power station, and about £0.5 million per MW for a CCGT. Running costs average approximately 0.7-1.5 pence per kWh for oil and coal, and about 1p per kWh for gas, but these costs are strongly affected by the fuel markets.

Solar power

Although the sun provides most of the earth's energy, and all chemical, wind, wave and hydro power can be classified as solar energy, the term is usually restricted to those technologies which involve the direct capture of energy from the sun's radiation. There are three different categories of technique:

passive solar heating
active solar heating
solar photovoltaic electricity.

Passive solar heating is a very old technology - a simple design like mounting large windows on the south-facing walls (in the Northern hemisphere) of a house, and good insulation on the northern walls is a passive solar system. Active heating is a little more complex, and requires a separate solar collector, for example a blackened panel mounted on the roof, to concentrate the solar heat. Most of these systems operate at a fairly low temperature (less than 100°C) and can only be used for water and space heating. Although it is, in principle, possible to raise steam for the generation of electricity, this is not thought to be a viable option in the UK due to the low levels of sunlight (sometimes referred to by the confusing term *insolation*).

Therefore, photovoltaics (PVs) are the only source of solar electricity which is of current interest in Britain. As the name implies, these systems rely on the photovoltaic effect: the ability of light (photons) to excite electrons in matter, and especially in semiconductors such as silicon.

Pure silicon has a crystal structure such that all the electrons are used up in bonds between silicon atoms. However, this pure material can be 'doped' by the addition of a small amount of another element (such as phosphorus) in such a way that the material develops an excess of free electrons which are not fixed to particular atoms. This gives it the ability to conduct electricity, and because electrons have negative charge, the doped material is called '*n*-type'. Different doping (for example with boron) can leave a shortage of electrons compared to the pure silicon structure. The 'holes' which are created in this way can also conduct electricity, and because they are regarded as having positive charge, the material is called '*p*-type'. If we can arrange for a layer of *p*-type material to exist next to a layer of *n*-type material, we have created a *p-n* junction, which is the basis of solid state diodes, and also photovoltaic cells.

Studying the energies of the electrons reveals that only certain specific values of energy are 'allowed', which we call energy levels. No electron in the material can have an energy which lies between energy levels - it must be inside one or another. In pure silicon, all energy levels are filled up to a certain value of energy, and the filled levels are collectively termed the valence band. Above this, there is a wide range of forbidden energies before the next group of energy levels. This group of levels is called the conduction band, because electrons which have been excited into it are free to move, and can conduct electricity. The gap between the conduction and valence bands is called the band gap, and in silicon, it is about 1.1 eV [the electron-volt (ev) is a tiny unit of energy equal approximately to 1.6×10^{-19} Joules] wide. This is the minimum energy required to excite an electron into the conduction band.

Because a *p-n* junction joins regions with an excess and deficit of electrons, it is energetically favourable for electrons and holes on either side to recombine, creating a region with no net population of charge carriers (the depletion region). Due to the opposing charge densities on either side, an electric field exists across the depletion region.

The photovoltaic effect occurs when a photon incident on the depletion region gives up its energy to an electron in the valence band and promotes it across the band gap to the conduction band, leaving behind a hole in the valence band. The electron and hole drift away from each other under the action of the depletion region electric field, giving rise to an electric current. We can harness this as a source of power by connecting an external circuit. Although this discussion uses silicon as a simple example, other semiconductors are also available for use. Absorption is strongest for photon energies near the band gap, which can be tuned to a certain extent by careful choice of materials. Band gaps between about 1.0 and 1.5 eV are suitable for use as a photovoltaic cell.

In practice, many refinements have been made over the simple principle discussed above. Multiple layers of junctions, perhaps with different band gaps, thin film structures, flexible 'coating' structures using small beads of semiconductor, reflector systems to improve light capture and anti-reflection coatings can all help to improve the power absorption in appropriate circumstances. In theory, these measures can provide conversion efficiencies up to 66% (compared with a theoretical maximum of 30% for a single cell) but the currently available technology only achieves around 16% on average.

Advantages

Photovoltaic cells have no moving parts, and so they are virtually maintenance free.

They can be mounted on buildings, which reduces the environmental impact - it is not necessary to dedicate tracts of land specifically to electricity generation, although this is also possible. In fact, free-standing solar cells can capture more energy if they are steered to follow the sun and ensure maximum illumination at all times.

If incorporated into building designs, however, photovoltaic cells can replace the building materials which would otherwise have been used for cladding, and this reduces the cost of the system overall. In fact, photovoltaic panels are now cheaper than polished stone cladding.

The potential resource is huge. It has been calculated that to generate the total of last year's electricity output for the UK would require photovoltaic cells over only an area equivalent to 2% of the land area. This is much less than the area occupied by commercial and industrial buildings.

Disadvantages

The first disadvantage of photovoltaic cells is the cost. It is a very expensive technology, currently working out around £2 660 per kW for a dedicated power station.

Operational drawbacks are intrinsic to the nature of solar power. There is more sun in summer, which means that photovoltaic cells can generate most electricity when demand is lowest. A similar argument applies to day and night, and this has led to the introduction of stand-alone systems for some commercial buildings, but they are less attractive for dwellings. Storage systems (batteries) can sometimes be used to improve matters.

Solar panels (of any sort) are very susceptible to bad weather, which again reduces supply just when demand increases.

Briefing Paper 2

Your Task

(1) Read this individual briefing pack which discusses the potential of some sources of energy. Pay particular attention to the points raised in the Overview Paper.

(2) On your own, prepare a short (3 minutes) presentation to your group of three on the viability of the resources you have studied. What advantages and disadvantages does each have in operational terms? How do they fit in to the current political climate? You will need to use numbers wherever possible in your approach so that comparisons can be made with other sources.

(3) The aim of your presentation is make the information known to your colleagues as clearly as possible so that, together, you can assess the relative potential of all energy sources. This is not a competitive effort. You are working as a team.

(4) After you have all given your presentations, discuss, as a team of three, which technologies seem to be most promising in terms of the information you have been given. You will need to consider what proportion of electricity you would hope to obtain from the different sources, and what level of investment is entailed. Your task is to offer advice to government, based on clear evidence, advice which is accessible to those with limited scientific training.

Hydroelectricity

Hydroelectricity is generated from the kinetic energy of moving water, using turbine systems. There are two principal types of installation: those that use the existing flow of water ('running river' systems), and those that generate the flow, from a reservoir or dam.

The water flow in a hydroelectric station is usually described by two parameters: the flow rate Q in $m^3\ s^{-1}$, and the effective head H. H is basically the height through which the water falls before it encounters the turbine, but reduced by factors which reflect the energy losses in the system, mostly due to friction and drag forces. The effective head is usually 75-95% of the actual height. It can be shown that the energy available is $10QH$.

This expression shows that the same energy can be produced either from a large volume of water with a low head, or a smaller amount of liquid falling through a long distance. The details of the turbine systems used can be optimised for high, medium or low heads, but the principles of operation are always the same.

Hydroelectricity has some major advantages as an energy source:

It is already well established in various parts of the world;
It is efficient;
Running costs are minimal;
It requires no fuel and produces no pollution;
The input matches well with annual changes in demand, being greater in winter (cold, dark and wet) than in summer;
Response times are short (10 seconds up to 1 minute), which helps to cope with short-term surges in demand.

Furthermore, hydro is one of very few techniques which can be used to store electricity, banking over-production at times of low demand, to be used when demand grows, through pumped storage schemes. In this type of system, excess energy (at night) is used to pump water from the lower reservoir to the top reservoir. During the day, the water then flows down again, generating more electricity.

Disadvantages are less obvious, and depend to some extent on the scale of the project. The initial costs of building a hydro station are comparatively high - around £2 million per MW - and this makes it difficult to mobilise funding in today's private economy.

Strange though it may seem at first, especially given the public perception of existing UK schemes, the major disadvantage across the world is environmental impact. Although hydro schemes produce no polluting gases, the construction of large-scale dams causes the devastation of the large areas of land which are flooded to provide the feed source, and since these are frequently in areas of outstanding natural beauty, there is some understandable concern about this activity. Examples like the Aswan High Dam in Egypt illustrate that the effect downstream can also be marked: the entire agricultural system relied on the annual floods to irrigate the land and provide nutrition. Now, it is dependent entirely on artificial irrigation and fertilisers, which are detrimental to the soil and the remaining river water. Meanwhile the silt collects in the dam itself, reducing its capacity year by year. Caution is therefore a touchstone in the hydro business, and even the comparatively small-scale installations which exist in the UK would require much more careful environmental impact analysis if they were being planned today.

Wave power

On an island like Great Britain, the sea is never far away, and we are only too well aware of its power. It is perhaps not surprising that many attempts have been made to harness the energy of the sea, in the form of waves. Wave power must not be confused with tidal power. Waves are produced by the wind blowing over the surface of the sea (which ultimately represents solar energy) and are characterised by small-amplitude oscillations of individual water molecules. Tides are caused by the gravitational pull of the moon, and represent bulk displacements of the whole body of water.

Many different devices have been designed to extract energy from waves, but they stem from three basic ideas:

(1) Building a head of water to drive a water turbine;
(2) Using the water's movement to drive air through an air turbine;
(3) Using devices which produce a 'pumping' action between moving and fixed parts.

(1) Water turbine systems

An example of the water turbine systems is TAPCHAN, which uses a *tapering channel* to collect water and drive it into a raised reservoir on the shore. The narrowing channel causes the wave height to increase, until the crests are high enough to spill into the reservoir. In fact, the channel acts very much like a horizontal funnel. From the reservoir, the water can be released through a water turbine, acting like a hydro scheme of low head and high flow rate. The principal advantages to this kind of system are that it is easy to build and maintain, as there are few moving parts and the technology is fairly simple, and that it has the ability to act as a storage facility, which is uncommon among wave power systems. Practical disadvantages are mostly concerned with the type of location which is required for efficient operation: there must be deep water close to the shore, and the tidal range must be small (less than 1 metre), otherwise the 'funnel' will not work properly. This small tidal range is not found in the UK, apart from at a few locations in the Shetlands, so 24-hour operation is impossible. A test site in Norway achieves a power output of 350 kW.

(2) Air turbine systems

A simple system using an air turbine is the oscillating water column (OWC) which has been in operation on Islay since 1985. Sea water is contained in a wedge-shaped chamber (made of concrete) which is open at the bottom, so that the water level in the chamber rises and falls with the wave action. This compresses the air above, which is driven through a special uni-directional air turbine, generating power on both the in and out cycles. The generator in the Islay installation has a capacity of 75 kW and runs off only one OWC.

More sophisticated systems have been designed using air turbines, coupled with flexible bags or floating chambers rather than fixed OWCs. The air turbines used in these systems are more sophisticated than water turbines, as they have to be able to produce power from both the rising and falling waves. However, the design exists and works well, so there are no development costs associated with this requirement. Again, these systems have few moving parts and so maintenance costs are low, especially in fixed rather than floating systems.

(3) Pumping systems

Perhaps a more obvious method for extracting energy from waves is to have a fixed base, either attached to the shore or the sea bed, and a floating body, moved by the wave action. The relative motion between the two parts can be used to drive hydraulics or other pumping mechanisms, which in turn can feed generators. The advanced technologies and difficult locations associated with wave power make construction costs high, perhaps even up to £13 million per MW. The marine environment is hostile, so much maintenance is required, and access problems increase maintenance costs yet further. Nevertheless, the natural resource for wave power in the UK is very large - a total of perhaps 61-87 TWh per year is technically achievable - and it could prove advantageous to exploit it.

Briefing Paper 3

Your Task

(1) Read this individual briefing pack which discusses the potential of some sources of energy. Pay particular attention to the points raised in the Overview Paper.

(2) On your own, prepare a short (3 minutes) presentation to your group of three on the viability of the resources you have studied. What advantages and disadvantages does each have in operational terms? How do they fit in to the current political climate? You will need to use numbers wherever possible in your approach so that comparisons can be made with other sources.

(3) The aim of your presentation is make the information known to your colleagues as clearly as possible so that, together, you can assess the relative potential of all energy sources. This is not a competitive effort. You are working as a team.

(4) After you have all given your presentations, discuss, as a team of three, which technologies seem to be most promising in terms of the information you have been given. You will need to consider what proportion of electricity you would hope to obtain from the different sources, and what level of investment is entailed. Your task is to offer advice to government, based on clear evidence, advice which is accessible to those with limited scientific training.

Tidal power

Tidal power, not to be confused with wave power, harnesses the energy of the moon to provide power. The basic principle of most systems is similar to low-head hydroelectric schemes: as the tide comes in (flood) the water is allowed in to the estuary. At high tide, a barrage is closed to trap the water at its highest level. As the tide falls (ebb) the trapped water is let out through turbines. This is called an ebb generating system.

It is also possible, although less favoured, to have the flood tide drive the turbines (flood generation) and schemes have even been suggested to operate in both modes alternately. This has the advantage that the power produced varies less over the course of each day, but produces less energy in total, as neither flood nor ebb can run to completion. Storage schemes can also be envisaged, where additional water is pumped into the reservoir during the flood, to generate more energy during the ebb phase. However, because the tide period is only 12 hours, this is a short-term storage option. Since the range of tides varies throughout the year, it can be favourable to adjust the mode of operation seasonally. It is even possible, in theory, to choose two sites which experience tides at different times, and so stabilise the average output of the combined system.

Consider a barrage which contains a body of water with uniform cross-sectional area A over a range R between high and low tide. The total amount of energy which can be extracted from releasing the water is $(rAgR^2)/2$, where r is the density of water, and g the acceleration due to gravity. (Check this by evaluating the potential energy stored in the water.) This energy is available from each high tide, twice a day. A French prototype system at La Rance generates 480 GWh (= 480 x 10^6 kWh) per year.

Tidal power is not a cheap option. Construction costs are £5-10 million/MW, and although there are no fuel costs, maintenance costs are relatively high, due to the hostile marine environment. There are also issues related to the change in drainage patterns, flooding caused by the reservoir, and resultant loss of mudflats and biodiversity.

Nuclear power

Nuclear energy is neither renewable nor fossil fuel. It therefore sits in the middle ground environmentally, between the fossil fuels which release large amounts of carbon dioxide and the 'clean' renewable technologies. The base fuel is uranium, which is mined in many parts of the world. Natural Uranium contains two isotopes, 235 and 238. It is processed to increase the proportion of ^{235}U and formed into fuel rods. These are mounted in a reactor chamber, where natural fission decays are allowed to occur. Each decay releases energy, in the form of heat, and fast neutrons. These neutrons can be slowed down by a *moderator*, to a speed where they can interact with other nuclei. When ^{235}U captures one of these neutrons, it becomes highly unstable, and quickly decays again, releasing more neutrons which can stimulate further decays. Thus a *chain reaction* is set up, which is controlled by the moderator.

The heat produced can be extracted by a cooling fluid (typically water or carbon dioxide under pressure) and taken off to a heat exchanger, where it is used to produce the steam to drive a conventional steam turbine.

Because of the strict safety measures which have to be in force, nuclear power stations are quite expensive to construct - around £1500 per kW - but the fuel itself is comparatively cheap, around £20 per kg. It may require, however, to be transported quite some distance, as the UK does not mine uranium. Overall running costs are in the region of 2p per kWh. Nuclear power is convenient to the generators, as it is reliable and response times are fast, so it is easy to cope with surges in demand.

The major operational disadvantage of nuclear power is the difficulty of storing the spent fuel. Under current regulations, it must be stored above ground in stainless steel canisters for 50 years. During this time, fission still occurs, and so the canisters must be cooled. After this time, cooling is no longer necessary, and it is intended that they be buried in a long-term disposal site. Under normal operation, the cost of disposal adds only 0.1 p to the cost of a unit of electricity. The need for long-term storage, however, has resulted in strong public opposition to nuclear energy, and recent events in Eastern Europe have only had a detrimental effect on the image of the nuclear industry

Wind power

Windmills have been used since before the Industrial Revolution to supply power for pumping water and milling grain. In modern times, the generation of electricity is the main focus of windmill designers, and they refer to them instead as wind turbines, or wind-powered generators. A very wide variety of turbines has been designed, with different shapes and numbers of blades, horizontal or vertical axes of rotation, and shielding strategies in the case of the vertical rotators. At the present time, however, it seems that the main contender in the UK is a horizontal-axis turbine, with three blades of aerofoil cross-section.

A quick calculation gives an appreciation of the energy available. For a wind speed of 5 m/s (a typical average wind speed in the UK), the power passing through a perpendicular area of 500 m² is 37.5 kW. This is the most common power available for a 500 m² turbine. However, the power varies as the cube of the speed, and so a small increase in speed will make a large change in the power available. The angle of incidence also makes a difference, and horizontal-axis turbines must be steered so that they face into the wind at all times. Some of the vertical rotators can avoid this requirement, but they are generally less efficient.

Clearly, wind turbines cannot operate in the absence of wind, but neither can they operate at too low wind speeds. Above that 'cut-in' speed, the power produced will grow with wind speed, until a saturation level is reached. This is called the rated power, and occurs at the rated wind speed, above which no additional power is generated with increasing wind speed. At very high speeds, turbines must stop operating to avoid damage. The aerofoil section used in the blades, together with the ability to adjust their angle, helps to obtain optimum power generation over a wide range of wind speeds.

The average cost of a wind generator is between £600 and £1000 per kW output, and the Renewable Energy Advisory Group estimates that there is a feasible resource of 55 TWh (10^9kWh) per year for wind power in the mainland UK, and at least as much again off-shore.

There are some very severe disadvantages of wind power, however. Clearly, it is highly seasonal, and cannot be used to cope with surges in demand, for example. The Renewable Energy Advisory Group suggests that the National Grid might only be prepared to accept 32 TWh (10^9kWh) per year from 'non-firm' sources. There is no 'off the shelf' installation, as each one must be optimised for the specific wind-speed characteristics of its site. Then there are the social factors associated with wind farms. By their very nature, a facility with many turbines will occupy a large area of land, and while 99% of this will still be available for cultivation, it may be felt that the turbines are a blot on the landscape - especially since the windy areas which are most suitable for use tend to be remote places, and regarded as areas of natural beauty.

In more developed areas, the aesthetic aspect is still a factor, but noise must also be considered, as the 'swishing' sound of the blades can be unpopular with local residents. Although this is not loud, it has the characteristics of a regular noise, and can therefore be intrusive and irritating. Although more noise is produced at higher wind speeds (or rather, higher speeds of rotation), the noise is more noticeable at low wind speeds, as there is less background noise directly from the wind to mask it.

These disadvantages must be weighed up against the strong advantages of wind power: it is plentiful, produces no emissions at all, and requires no fuel of any kind. The running costs are therefore very low, after the installation has been completed.

Your Group Task

Each of you has now studied three main energy sources. You should be able to brief each other on the potential of these sources to assist in meeting the Renewable Obligation commitment.

(1) Each presentation should last about 3 minutes and be given uninterrupted.

(2) After each presentations, questions may be asked to clarify issues raised.

(3) As a group discuss the information and try to come to some agreement on which sources have the most potential in assisting to meet the Renewables Obligation. Be quantitative.

(4) As a group, you are asked to give a 5 minute presentation to the Secretary of State, summarising your findings and making your recommendations. You will be given one blank overhead projector transparency and the presentation can be made in any way you wish. If you require extra funding, make a good case for it.

Renewing Energy

We should like to know your reaction to the material you have just completed. Please answer the following questions as honestly as you can.

(1) Tick *one box for each line* to show your opinion:

Studying Energy supply is

Straightforward	☐	☐	☐	☐	☐	☐	Complicated
Boring	☐	☐	☐	☐	☐	☐	Interesting
Irrelevant to me	☐	☐	☐	☐	☐	☐	Relevant to me
A meaningful experience for me	☐	☐	☐	☐	☐	☐	A meaningless experience for me
Hard to visualise	☐	☐	☐	☐	☐	☐	Easy to visualise
Clear	☐	☐	☐	☐	☐	☐	Confusing

(2) Tick the box which *best reflects your experience* of *energy* (as a topic you have studied):

	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
I found the the study of energy full of difficult ideas	☐	☐	☐	☐	☐
There is too much information to absorb	☐	☐	☐	☐	☐
The study of energy has made me more aware of pollution	☐	☐	☐	☐	☐
The idea of energy is far too abstract	☐	☐	☐	☐	☐
There are too many forms of energy to grasp in one go	☐	☐	☐	☐	☐
The study of energy is not relevant to my life	☐	☐	☐	☐	☐
It has helped me to use energy more efficiently and economically	☐	☐	☐	☐	☐

(3) Thinking about *the material you have just completed, tick the box which best reflects your experience*:

	Strongly agree	Agree	Disagree	Strongly disagree
The material helped me to spot the areas where I had difficulty	☐	☐	☐	☐
I think I am more aware of the importance of the issues raised	☐	☐	☐	☐
I can 'see' some of the ideas better now	☐	☐	☐	☐
I did not have enough time to complete it properly	☐	☐	☐	☐
Compromise between economics and pollution is important	☐	☐	☐	☐
I do not like the style of the material	☐	☐	☐	☐
I understand the economic and political energy debates better now	☐	☐	☐	☐
I understand the meaning of energy better now	☐	☐	☐	☐
Working as a group helps me to understand better	☐	☐	☐	☐
Working in a group is a very important skill for my life	☐	☐	☐	☐

(4) The most difficult aspect of studying energy, in my opinion is

....

....

(5) The most helpful part of the material I have just completed was:

....

....

Thank You for your help

Centre for Science Education, University of Glasgow