

**An Evaluation of the Effectiveness of Video and
the Formulation of Hierarchical Models of
Student Understanding in Mechanics**

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Abstract

An Evaluation of the Effectiveness of Video and the Formulation of Hierarchical Models of Student Understanding in Mechanics

by

Edward Graham

This thesis reports on research into two areas. Firstly the evaluation of the effectiveness of video as a resource for the teaching of mechanics and secondly investigations into student understanding of mechanics concepts.

The first of these two areas has been based on a controlled experiment, used to determine whether the use of video can lead to improved levels of student understanding among sixth form mathematics students. The data that has been collected from this experiment has revealed that there are virtually no statistically significant differences between the understanding of the control and experimental groups involved in the experiment. However, student reactions to the videos, recorded on questionnaires, have provided much valuable information. From this it has been possible to identify the most effective way to use video in mechanics. This approach has been applied to the production of two videos, which have been used to validate and refine this approach to video production.

The second area of research developed from the first as the responses of the students to the questions used to test understanding in the experiment became available. The results from the pre-tests produced a wealth of information about the intuitive reasoning used by many students. Their intuitive ideas include many misconceptions, or ideas that are at considerable variance with scientific thought. In addition the responses to the post-tests yielded information about the state of students understanding and the ways in which it had developed from the intuitive levels observed in the pre-tests. The data gathered from the post-tests allowed a small scale pilot study to take place, which investigated the feasibility of modelling the development of student understanding using a set of hierarchies. This technique was then applied to the two concept areas of force and momentum on a much larger scale. This thesis provides details of the models developed in this way and the intuitive reasoning used by students.

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CHAPTER 1 - INTRODUCTION

1.1 Background to the Project

The learning of mechanics by students has for some time been a matter of some concern to those involved in its teaching. It has become clear from research from many sources, but for example that of Clement (1980) that students are forming strong alternative understandings of important mechanics concepts. These alternative concepts then hinder the development of further ideas and often handicap students greatly when they attempt to apply their knowledge of mechanics. This problem has been highlighted by the reports of physics teachers, particularly those working in America, but British work has also taken place in this area. Berry, Savage and Williams (1990) have worked with mathematics students entering undergraduate courses and identified many of the problems that have also emerged with physics students. In addition they also highlighted some of the reasons why A-level courses are failing to enable students to obtain a good understanding of mechanics.

There have been many suggestions put forward as to how to improve this state of affairs and many of these have included the use of video. However although there has been much speculation that video can help to improve student understanding, little firm evidence has been provided to support these claims. Hake (1987) has used video as part of a course that produced improved levels of student understanding, but this course also included many other new initiatives. One aim of this research project was to undertake an experiment that would provide evidence that could then determine whether or not video has the potential to lead to improved levels of student understanding.

Since the publication of the Cockcroft Report (1982) many of the new teaching initiatives have adopted approaches in line with the suggestions of paragraph 243. This paragraph stated that good classroom practice would include opportunities for exposition, discussion, practical work and investigation. These activities have become part of the new initiatives such as GCSE and the new School Mathematics Project (SMP) Mathematics 16-19 course,(see Dolan (1988)), but have not yet been incorporated into any other A-level courses. The time that will see this extension is not far away as the School Examinations and Assessment Council (SEAC) are reviewing the role of A-level courses. In particular one of the new principles put forward by SEAC (1990) is that there should be continuity and progression from GCSE and Key Stage 4 of the National Curriculum into A-level. This will most probably see the components of good practice identified by Cockcroft (1982) as part of all mathematics A-level courses by 1994.

In view of the new initiative by SMP and the impending review of A-level courses, it is likely that there will be a period of intensive syllabus development, with many new initiatives being introduced. Clearly there is a strong possibility that many of these new initiatives will make use of video as SMP have already done. In view of this and the reports like that of Berry, Savage and Williams (1990) which indicated that the medium of video has been under-used, the research also attempted to establish the most effective way to use video in the teaching of mechanics. This area of the research would be of particular value to the producers of new video resources in order to ensure that the video is used to communicate with the students the aspects of mechanics that are best taught using this medium.

It was also anticipated at the outset that during the course of the study further information about student problems in mechanics would be generated, which

could also be of value to both teachers of mechanics and those involved in the development of new resources.

1.2 The Development of the Research Work

The broad aim of this research project was summarised in the application for the approval of a research project for a polytechnic-funded research post, submitted in 1987. This summary reads:

"The research project will compare the learning experience of different groups of A-level mathematics students with and without using video. One of the objectives of including video in a teaching package is to provide motivation and relevance of mechanics to reality. We will also assess whether video can help in the understanding of the basic concepts."

In the same document six key proposals for specific areas of work were identified, which would form the basis of the work undertaken by the research student. These six areas of work are listed below.

The researcher will;

- (a) evaluate the material that is currently available,
- (b) propose material that is needed to be developed,
- (c) collect statistical data from different groups of A-level students (some using video and some not doing so),
- (d) provide a theoretical analysis of this data using statistical packages such as MINITAB or SPSS,
- (e) propose effective means of assessing basic concepts in Mechanics,

(f) propose the most effective use of video as a teaching resource in Applied Mathematics.

Work on the research project began in January 1988 and initially concentrated on two main areas. The first of these was a comprehensive literature review covering the two areas that were of interest. For the video aspect of the project the use and evaluation of video as a teaching resource and in particular with reference to applied mathematics was reviewed. Also from the mechanics viewpoint, literature relating to student understanding and the difficulties that students experience with the basic concepts of mechanics was reviewed. The findings of this review are reported on in chapter 2 of this thesis.

The second area of work initially undertaken was the review of existing video resources for the teaching of mechanics. The catalogues of the British National Film Institute (1963-1990) proved a useful means to assist in the location of many of these resources. As the videos were reviewed a guide that would be of use to practising teachers was prepared. This provided detailed information about the content and suitability of the videos as well as about their length and availability. An overview of where many of the videos could be used was provided in the form of a table which indicated the resources which would be appropriate for specific A-level courses. This guide was to be of considerable value during the design of the experiment. It was also continually updated during the course of the project and copies made available for interested teachers. Chapter 3 of the thesis looks at the findings of the review including an assessment of how the currently available video resources provide for contemporary mechanics courses, while appendix A contains a copy of the latest version of the guide. This part of the work effectively covered areas (a) and (b) of the proposal.

The next stage in the development of the research, necessary to permit area (c) of proposal to take place, was the setting up of an experiment in which the learning experiences of the students with and without video could be compared. As a first step the criteria which the experiment should ideally satisfy were identified, before any approaches were made to any schools or colleges. The second step was then to locate an establishment or establishments where the experiment could be performed. This proved to be considerably more difficult due to various problems, such as school size and differences between schools. Eventually Exeter College was found to be a suitable establishment with several staff willing to participate in the project. The actual experiment eventually ran for just over two years from October 1988 to December 1990, during which time a good deal of data was collected. However as with any experiment that runs for this length of time there were some problems caused by a lack of continuity. The setting up of the experiment and the problems encountered as it progressed are described in chapter 4 of this thesis.

Once the outline of the experiment had been established, it was necessary to decide how to collect data that could be used in an analysis and lead to determining an effective means of using video. The decision taken was to develop questions that would test students understanding of the concept-areas covered in the teaching associated with the experiment. In particular these questions would not test the mathematical skills needed to solve problems completely, but concentrate on the understanding of concepts needed to begin to solve problems. Some of the questions developed were closely linked to existing research, but many new ones were also developed. They all took a format that was very qualitative. In addition to these questions to test understanding, questionnaires were developed to measure the reactions of the students and staff to the videos. The development of both these tools for collecting data are described in chapter 5 of this thesis.

concept-area. As the students' responses are reported, the strategies that had been used to obtain them are also presented.

An analysis of the students' responses to the questions that were associated with the concept-area of force were also used to formulate a pilot model of the way that students understanding of this concept-area develops. This model took the form of a hierarchy composed of three levels, each of which represented a different degree of understanding attained by the student. The results of this initial investigation were interesting and so a larger scale survey was undertaken, which confirmed the validity of the initial model with only a few minor modifications. This particular aspect of the research has shown how research methods applied in different areas of mechanics can be applied to mechanics. Chapter 9 describes both the results of the initial analysis and of the larger scale survey. This empirical study has not only confirmed that the problems associated with force, identified in previous research exist, but has given a new insight by determining the stages that students pass through as their understanding develops.

As the method of investigation used in chapter 9 had been successful it was also applied to an investigation of student understanding of the concept-area of momentum, which has not been the subject of much previous research. This was used to formulate a further model of the development of student understanding, which is described in chapter 10. As for the work in chapter 9 on force, this model reveals for the first time, the way in which students' understanding develops, rather than just highlighting individual problem areas.

The work contained in chapters 8, 9 and 10 provides valuable information for all teachers of mechanics. It identifies the initial state of student understanding and how this progresses in two concept-areas as the students are taught. Thus it can

make teachers aware of the problems they will initially encounter and the way in which their students will assimilate ideas as they are taught.

CHAPTER 2 - THEORETICAL FRAMEWORK FOR THE STUDY AND LITERATURE REVIEW

2.1 Introduction

A great deal of research into student understanding of mechanics has taken place in recent years. Much of it has focussed on what have become known as misconceptions, preconceptions or alternative conceptions. All of these terms refer to ideas that students have assimilated into their cognitive structures, integrating them so well that a true understanding of a concept becomes almost impossible. There have been many studies, such as that of Clement(1982), which have described how some simple alternative conceptions can remain hidden and in fact cope with simple situations, but prevent the students grasping an understanding of the concepts at higher levels. A further example of this comes from the work of Jagger(1987) who describes how many students have an understanding of acceleration that is adequate for one dimensional situations but not for any in two or three dimensions.

The presence of these misconceptions in student understanding is very widespread in countries throughout the world, and in all aspects of mechanics. It is of particular interest that there is a great deal of similarity between the results of research carried out in different parts of the world. The presence and extent of these misconceptions can be attributed to several causes, but the most influential of these seems to be the students own experience of the world around them. Because of the presence of motion, forces etc. wherever they look, there is a desire to explain these situations in their own minds. Many of the ideas that these students have formed have strong resemblances to stages in the historical development of an understanding of the concept, without some of the great

insights that have helped develop the understanding that exists today. One common example of this is with students' understanding of the relationship between force and motion. Whitaker (1983) noted that many students' conceptions are remarkably similar to the ideas put forward by Aristotle. There are also numerous other cases where student expectations based on their experience of the real world are at variance with reality. Other reasons for these misconceptions include the fact that there are some teachers who themselves have the same misconceptions, as their students.

Several attempts have been made to describe how students learn, particularly with regard to how their understanding develops. Some research has concentrated on particular topics while others have looked at learning in a more general context. Some empirical studies have formulated models which include stages or levels through which student understanding passes. Trowbridge and McDermott (1981) have used this approach to some extent with the concept of acceleration by classifying the approaches taken to a particular problem by students on interview. In Britain an extensive study, by the Concepts in Secondary Mathematics and Science (CSMS) team, lead by Hart (1981), has used an empirical approach to formulate levels of understanding for secondary school mathematics topics.

As more knowledge about student misconceptions and the ways in which students develop their understanding of concepts has become available there have been an increasing number of attempts to improve student understanding of mechanics. Many of these have supplemented existing teaching methods with new ideas. Often these have been designed to cause cognitive conflict for the students or included diagnostic tests to identify misconceptions. They then provide remedial or alternative developments of the concept for the students to consider. In some cases, such as that of Hewson (1985), the approach has simply

been to test for and then remedy one misconception, but others such as those of Hake (1987) and Borghi et al. (1987), have tried to take a new approach to the entirety of the subject area.

Several of these new initiatives have incorporated the use of video as an integral part of their programme. Hake (1987) for example has conducted an evaluation of his new course, comparing it with more traditional courses run at similar institutions. His work indicated that there was a considerable difference between the outcome of the two approaches, with his students producing better results. However this evaluation did not reveal the extent to which video had played a part in facilitating this improved performance. Berry and Huntley (1986) have described how video has a great potential for use in the teaching of applied mathematics and engineering, as have several others, but none have provided evidence to demonstrate that the video does actually contribute to improved understanding.

There has been much said about the evaluation of video and other educational media. Ely (1987) has reported on the way that the evaluation of media in education has developed, briefly from a very summative approach assessing how well it taught to a much more formative approach which finds the best way to teach through that particular media. Bates (1981) also recognised the need for research to become less concerned with rigorously controlled experiments but to move towards a format that would help producers of educational video to develop the most effective resources.

This research project has been undertaken to investigate whether video has the potential to improve student understanding of mechanics, by providing a controlled experiment which will evaluate the effectiveness of video as a teaching medium for mechanics. In particular it will concentrate on whether or

not student misconceptions can be overcome. However it will also provide an opportunity for formative research to identify the best way to use video in mechanics teaching and provide information for producers about the best approaches for videos to take when communicating ideas to students.

As well as the investigation into the effectiveness of video the research will also explore the development of student understanding of certain concepts with British students following A-level mathematics courses that include mechanics. This aspect of the investigation will attempt to formulate hierarchies of understanding for the concepts involved.

Each of the sections in this chapter explores an aspect of the existing research to provide a setting for the current project. The research into student understanding of mechanics is considered in section 2.2, while section 2.3 examines studies into the way in which students develop concepts. New initiatives in the teaching of mechanics are examined in section 2.4, while section 2.5 specifically examines the use of video in mechanics. The evaluation and use of this medium is discussed in section 2.6, with the final section 2.7 looking to the future and examining the potential of interactive video as a resource.

2.2 Student Understanding of Mechanics Concepts

Considerable research into student understanding of a wide range of topics within mechanics has been carried out in recent years. The main problem associated with topics in mechanics is that of preconceptions or misconceptions. These have been discovered in all areas of mechanics, and consist of incorrect interpretations or explanations of physical phenomena. Not only have they been found right across the range of mechanics topics, but also in students of all ages and abilities. The misconceptions arise because students form their own

explanations of what is happening in the world around them from their own personal experiences. These explanations are often very similar, and it is this consistency among students that is perhaps most alarming, because it means that different students are reaching the same incorrect conclusions about concepts in mechanics quite independently. Misconceptions also arise when students do not fully understand a new concept and allow their intuition to guide their reasoning. While many of these studies have examined student understanding of a range of concepts, in depth studies have been undertaken for several topics within mechanics.

In most of these studies understanding has generally been defined as the ability to apply a knowledge of mechanics to a physical situation, rather than to the solution of text book problems. A large difference has been found in students between these two measures of understanding, with the former being regarded as the more accurate indicator of a students' understanding of a concept. Success on the latter often depending only on the use of memorised techniques and formulae that require little or no real understanding.

One of the most fundamental concepts in mechanics is force, which has been the subject of many investigations of student understanding. Warren (1979) has produced an extensive account of the various problems students find in their studies of force, and used test questions to establish the extent of them. With Newton's laws various stumbling blocks were identified, that hindered student understanding and their application of the laws. The overwhelming problem associated with the first law arises from the fact that in real life students do not encounter uniform motion in the absence of all forces. Consequently this leads to the belief that a force is needed in the direction of motion if it is to continue. The problems with the second law lie not with its application, but with the identification of the forces that are present and the finding of their resultant. The

third law is extensively misunderstood and misinterpreted, often due to the way in which it was stated, with many students believing that the two opposing forces act on the same body. In addition to these fundamental problems there are also many particular situations where specific difficulties arise, for example in circular motion. Warren concludes that if force were to be recognised as a difficult concept and treated as such, it would become much easier for students to understand it in mechanics classes.

Viennot (1979) has studied the way in which students reason when they are tackling elementary problems in dynamics, in particular the way in which they associate force with velocity. She discovered that there is a definite belief among a large proportion of students that the force acting on an object is proportional to its velocity, and that if it is at rest then no forces can be present. She also made the disturbing observation that many students only consider pairs of action-reaction forces to be equal if there is no motion, and that the action force is greater than the reaction force if there is movement. A set of rules, comparable to Newton's laws, that modelled the way students reason in dynamics problems was set out as a result of this research.

This line of inquiry has been taken further by Clement (1982) who was able to find substantial evidence to support the presence of the "motion implies a force" preconception in very simple situations, such as in the motion of a pendulum or a coin that is tossed. He draws a parallel with the historical development of the theories of motion and the ideas of Aristotle and Galileo. The similarity of these arguments and this preconception helps to explain the widespread use of it by students, and the way it appears to them to be an acceptable explanation of their observations of motion in real life. Clement concludes that it is essential that teachers do not begin instruction without considering the very strongly held

ideas that students have formed for themselves, and use these as a starting point for their teaching.

This parallel between student understanding and the historical development of the theories of motion was also discussed by Whitaker (1983). His study was based on student responses to questions, both before and after instruction, on trajectory motion which again revealed many of the same type of misconceptions. That students thought that a force was needed to maintain motion was apparent, along with the idea that motion quickly stopped when the force was removed. He also noted that students tended to drastically overrate the importance of air resistance to support their arguments. Whitaker has tried to remedy these problems by challenging students at an early stage using a technique that will be described in section 2.4. He concludes his study in the same way as Clement (1982) and says that he feels students need to be confronted with their misconceptions and shown their inadequacies before they can begin to cope with a course in mechanics.

There are other instances such as the work by Roper (1985) which have confirmed the presence of these misconceptions. He again identified a strong belief that a force must be present to maintain motion and considerable confusion with Newton's third law, possibly caused during teaching by only considering the forces on one body and not identifying the action-reaction pairs of forces. A very weak understanding of gravity was also clear in some students.

Watts and Zylbersztajn (1981) not only looked at student understanding, but also teacher awareness of student difficulties. Although the teachers were able to predict some of the incorrect responses, there were several areas where the teachers were less aware of the way that their students were reasoning.

Halloun and Hestenes (1985a) have developed a diagnostic test, specifically to assess the state of understanding of new entrants to mechanics courses. This test covers many aspects of mechanics, rather than more restricted aspects of it, which has been the case for most of the previous research described here. Also it was suitable for use both before and after periods of instruction, so that comparisons of improvements in student understanding could be made. The test was used with several different groups following introductory mechanics courses, providing results that indicated a poor gain in student understanding. This caused concern, as it was obvious that many students were not using Newtonian reasoning, still allowing their preconceptions to dominate their thinking, even after a course in mechanics.

This research was continued in a classification of student beliefs about motion, by Halloun and Hestenes (1985b). This classification was based on results obtained from their diagnostic test as well as other sources. Students were categorised into three groups depending on the type of reasoning they used when solving problems, as being either Newtonian, Aristotelian or impetus based. From their studies and the findings of other researchers they put together a taxonomy of students' intuitive ideas about motion. This forms a very important starting point for any new approach to the teaching of mechanics, because it sets out the problems that have to be overcome. If the teacher knows the methods that students are likely to try and use, he can draw attention to the inadequacies of these methods and hope to give students a reason for changing to a Newtonian line of thought.

The development of misconceptions has not been confined to mechanics or to certain groups within the student population. Peters (1982) has looked at the presence of misconceptions among the most able physics students, not only in mechanics but also in other areas of physics. Here with a very able group, who

received special attention, misconceptions were identified with the help of examination questions and exercises designed to probe conceptual understanding. Peters concluded that if this able and privileged group of students has problems, then the remainder of the student population must also have similar misconceptions. He also felt that students were often addressed by lecturers at a level that is really too high for them, and that a new approach is needed for the teaching of introductory physics courses.

In a recent study Gunstone (1987) has used a large scale survey to establish the extent to which these misconceptions are held by high school students. For this purpose he was able to include in a state examination, covering over five thousand students, five questions that had been previously included in studies of understanding. His results clearly indicated that certain misconceptions were widely held by students, but it was suspected that the results underestimated the true extent of them. The reasons for this being that some of the problems had been used on teacher in-service courses so that many of the students may have been familiar with them, and secondly that the correct answer had to be placed in front of the student because of the multiple choice format. This raised two problems that need to be considered in research design, especially the second, as students may respond differently to a question when the correct response is present on paper than to the same question in a different situation. He also stated that asking for explanations to answers may have helped to identify the processes that students were using and could have led to more information about the misconceptions.

Having seen how widespread misconceptions were among students that he had encountered Helm (1980) tried to determine the causes of some of them. He began by administering a multiple choice test to groups of first year undergraduate students, school students and teachers. It was clear from the

results that misconceptions were strongly held by both groups of students and also by some of the teachers. This poor performance by some of the teachers was suspected to be a possible factor contributing to the spread of misconceptions, as were the misleading approaches to concepts found in some textbooks. The fact that most physics problems were very formal and abstract in nature while most students were still at a concrete reasoning stage, did not help to improve student understanding. Helm concluded that there was no single cause of misconceptions, but that it is important for teachers to be aware of them so that they can help students to correct them. It is also essential that any confirmation or encouragement of misconceptions is avoided.

Student difficulties have been apparent not only in the understanding of concepts but have in addition come to light through the application of mathematical techniques to mechanics problems. McDermott et al. (1987) have reported on the difficulties that physics students have relating physical concepts to graphs, particularly in the field of mechanics. These difficulties can be grouped into two categories, firstly with the extraction of physical information from graphs and secondly with the transfer of physical data to graphs. Within the first of these categories the problems are associated with an inability to decide what feature of a graph is associated with which physical concept. The second category of problems arises when students try to represent physical situations such as motion on a graph. In particular they find it hard to use the relationships between position, velocity and acceleration graphs. As a result of this study the recommendation is made that graphs are used whenever possible, especially in connection with motion, in order to familiarise students with them.

An investigation of student understanding of acceleration in two dimensions has been undertaken by Jagger (1987), with an emphasis on situations where constant speed is involved. In this case there is a definite trend to assume that the

acceleration is zero because the speed is constant. This misconception stems from the fact that acceleration is commonly associated with increasing speed as opposed to changing velocity. The word acceleration seems to have two different meanings one for the general public and another for the mathematician. Acceleration is a difficult concept anyway and this terminology problem means that students think they understand the problem when they actually do not. Suggestions made for improving this include; teaching acceleration as a vector quantity at all stages, demonstrating to students that their ideas do not match the mathematical definitions and providing opportunities for discussion about the concept, possibly stimulated by practical work.

A report on secondary school students' understanding and use of the concept of energy was prepared by Brook and Driver (1984), from responses to questions administered by the Assessment of Performance Unit and a small number of interviews. Their research indicated that often students had two meanings for the word energy, one intuitive and the other scientific, which were both quite different. When considering a situation some students used energy in either an explicit or implicit way, but a considerable proportion preferred to try to use observable quantities, like velocity and steepness, instead of the abstract quantity energy. There was a very obvious tendency for them to associate force, friction and movement with energy, especially when conservation of energy was considered. Interestingly students were found to be able to reason correctly in certain everyday situations regardless of their scientific backgrounds, illustrating how intuitive ideas can explain familiar situations but cannot be extended to others.

The work-energy and the impulse-momentum theorems were the subjects of a detailed investigation of student understanding undertaken by Lawson and McDermott (1987), using a demonstration interview technique. Two pucks of

very different masses were subjected to the same force while they moved from rest over the same distance on an air table, and then the students were asked to compare the momentum and the kinetic energy of the two pucks. For a correct response the student had to apply the definition of impulse realising that the larger mass took a longer time to travel the distance so that the impulse was greater and hence the momentum was greater for the larger mass. For the kinetic energy comparison it was necessary to see that the work done was equal in both cases, since the force was applied over equal distances. From the interviews it became clear that the students found it difficult to use the correct theorem in solving these problems, although they had all been successful in solving text book problems based on them. Two common arguments appeared in addition to the correct one. The first of these was a compensation argument based on the fact that the larger mass had a smaller velocity and therefore had momentum or kinetic energy equal to that of the lighter, faster moving puck. The second argument was based on the observation that the two forces were equal and that therefore the momentum and the kinetic energy of the two pucks were equal. In addition there were also confused arguments that could not be classified.

Earlier work by Backhouse (1964) had indicated that there was also considerable confusion about momentum and kinetic energy. His investigation showed that many students could not differentiate between the two concepts.

McCloskey et al. (1980) have investigated student beliefs about the motion of objects moving in circles or spirals when the constraining forces were removed. Students were asked what would happen to a ball when it left a curved tube in which it had been moving. In a significant number of cases, at least 30%, the students stated that the curved path would continue or gradually fade away. Another question concerned the motion of an object being swung round in a circular path on a piece of string, if the string breaks. Only just over 50% of the

students were able to give the correct response to this, while others thought that it would move in a spiral or along a radius. This report concluded that student misconceptions about all aspects of motion need to be addressed, identifying the fact that teaching may sometimes simply give students the terminology to describe their misconceptions.

Thus there is a substantial amount of research that has identified problems in student understanding of mechanics, which have in many cases been in the form of misconceptions. These misconceptions are not limited to any one area of mechanics but can be found in all aspects of the subject. The extent of these misconceptions is considerable, with students in different parts of the world having the same problems, which often reflect stages in the development of knowledge in the past. The overwhelming conclusion reached by the researchers working in this field is that there is a need to challenge the students beliefs about the concepts of mechanics and demonstrate the weaknesses of the students' ideas before the subject can be developed.

2.3 The Development of Student Understanding

As well as the studies that have identified misconceptions, which have been discussed in section 2.2, a number of in depth studies have been undertaken for several topics within mechanics. Some of these have revealed a particular obstacle to the understanding of a concept, while others have been able to set out a series of steps or stages through which understanding develops. These stages can show the type of reasoning used at each level and the order in which they develop, providing a firm basis for the designing of future teaching of the concept. Where a specific problem arises, recommendations to solve it have usually been made by the researchers. Most of this type of research has been based on the results of extensive interviews with students.

Detailed research studies into the understanding of concepts in kinematics have been carried out, which have probed into the way in which understanding of the concept is built up. This type of study has made extensive use of interviews with students, often centred on a demonstration or practical problem.

One of these is Piaget's (1970) study of the child's conception of speed and distance. This used demonstration interviews to gather data, that enabled the classification of stages through which the child passes on his development of an understanding of the concepts. In addition, these stages also relate to the child's intellectual development, whether it is at an intuitive, concrete or formal reasoning level. The development is traced through changes of location and displacements to comparisons of movements and speeds. The comparison of two different systems where movements are seen in succession and the motion of uniformly accelerated objects completed the study. Piaget explained how it is essential to master one idea before the next can be understood, for example, until a child understands displacements he is unable to compare speeds correctly. If he has not grasped the concept of displacement the child will compare speeds by considering the order of the objects, as this is the only criterion that such a child can use. Thus a child's development of these concepts depends on his ability to handle the next level of operations and the previous concepts, before progress can be made.

In depth studies of velocity and acceleration in one dimension have been undertaken by Trowbridge and McDermott (1980, 1981). Both of these studies utilised demonstration interviews, where a demonstration that took place formed the basis of the interview, as the primary source of data. Written tasks were also administered to help gather more information. In both these studies, as in many others, understanding of a concept was defined as the ability to interpret or

explain a physical situation, rather than to give a definition of it or answer standard problems.

For the velocity study the Piagetian motion tasks were initially considered, but these were found to be too easy for the students and two velocity comparison tasks were eventually developed. From the interviews with students it became clear that the main cause of problems was the belief that two objects had the same velocity if they were at the same point. Even though students could correctly define velocity and use it in written exercises, they tended to revert to their intuitive preconceptions when confronted with a real problem, thus confirming the doubt about using examination type questions as a measure of student understanding. From their observations, the investigators noted that many students failed to make a connection between their preconceptions and the concepts that they had been taught in the classroom. Concluding this study the researchers felt that this type of detailed examination of a concept would be of value to teachers, because it identified the way in which student reasoning develops from using a position criterion to an effective method.

Trowbridge and McDermott (1981) carried out further detailed research into the understanding of the concept of acceleration in one dimension. They were particularly concerned with the interpretation of acceleration as the ratio of change of velocity over change in time. Two acceleration comparison tasks were set up for use in demonstration interviews. From the student responses to these tasks ten different procedures used by the students were identified, which were then classified into five types of approach to produce a hierarchy of levels of understanding. These approaches were totally non-kinematic, linking acceleration with position, linking acceleration with velocity, use of change of velocity with no regard to time and a correct interpretation of the ratio. As a student becomes able to use an approach further along the list he is able to

demonstrate a better understanding of the concept. As with the velocity study it became apparent that although students could define the concept and produce formulae relating to it, they were unable to explain a physical situation or apply these formulae to it correctly.

A major research project that spanned several years was the CSMS work, led by Hart (1981). The basis of the work was to formulate a set of hierarchies, for different topics on secondary mathematics courses, that modelled the development of student understanding in these areas. The levels forming these hierarchies were established using an empirical analysis of the responses of large samples of students to test questions that were initially developed using interviews with students. Although this work did not include mechanics it does provide a basis that can be adapted for the formulation of hierarchies for other areas of study.

In addition to the investigations about specific topics in mechanics, some research has taken place into the ways in which students form concepts and the way in which teaching affects them. From this type of research conclusions about the best methods to use for the teaching of mechanics can also be made.

The ways in which students acquire concepts and modify them as a result of their education and experiences has been studied by Leboutet-Barrell (1976), based on observations from his own research and that of others. It appears that when children start to use words like force, mass and speed they do not have the same meaning as for a scientist. The very young child's version is a very loose concept defined only by their observations. As the child grows up these concepts become better defined, in terms of their characteristics, but even so considerable difficulties can be encountered in trying to change a child's ideas about physical concepts. Work with undergraduates has demonstrated how some

misconceptions are still present in these students. In the light of these observations Leboutet-Barrell concluded that more research was needed to give a greater understanding of the way in which concepts are developed and to use this in the development of new teaching strategies.

The different methods by which scientific concepts may be taught and the learning resulting from these approaches has been analysed by Gilbert, Watts and Osborne (1982). They began by defining four interpretations of the understanding of scientific concepts, belonging to the child, the teacher, the curriculum and the scientist. From the process of teaching various outcomes are possible. On the one extreme it can leave the child's ideas (including his preconceptions) unaltered, or the teachers view may be learned while the child's ideas remain dominant, even sometimes with the teaching being used to justify misconceptions. A combined approach is possible where some misconceptions are used alongside correct principles . The ultimate aim of the teaching is to instil a complete understanding of the concepts in the child. For this to take place it is essential that the child's initial state is considered and that the teacher does not try to impose his version of the concept on the child. In order to achieve this an atmosphere should be established in which different ideas can be freely aired and confronted, leading ultimately to a universal understanding of the concept.

The intellectual development of physics students has been studied by Renner (1976). He discovered that although most of the teaching taking place in physics assumes that the student is capable of formal, abstract reasoning, many students have not reached this stage and are still at the concrete stage. For these students formal ideas are meaningless and do nothing to promote their intellectual development. Formal thought develops from interaction with concrete situations and not from exposure to formal ideas. In physics practical work provides an ideal opportunity for this interaction, but its value is often lost because it is

preceded by abstract theories. To make practical work promote intellectual development it needs to be used in an exploratory manner, with the results being used to formulate concepts. The high mathematics content of many physics courses involves many formal processes and can act as an obstruction to the understanding of concepts. Renner has reported successes in improving intellectual development by the use of this approach. Another example of practical work being used in this way has been developed by Berry and Graham (1990). In this case students are initially presented with apparatus and asked to familiarise themselves with it. They are then asked questions which probe their understanding, before undertaking experiments designed to allow students to explore their answers to these questions.

The attempts to produce models of the development of student understanding of concepts have all been based on an analysis of data gathered either through the use of interviews or test papers. Most of these studies have examined general aspects of the development of understanding, concentrating on the cognitive processes initiated by teaching, the relationship between students ability to assimilate concepts and their ability for formal as opposed to concrete reasoning and the influence of factors around the students on their development. The studies on particular concepts provide more specific models for that area and the work in mathematics illustrates a method that could be applied to a wider range of concepts including those of mechanics. The findings of this research are important, as they allow any new teaching resources that are produced to be tailored to the way in which student understanding develops. While the general research provides an overall framework for instruction, the studies on individual concepts illustrate the specific approach for that concept.

2.4 New Teaching Initiatives

Various attempts have been made to improve the teaching of mechanics with a view towards improved student understanding. Some such as Hake (1987) have considered whole courses while others such as Hewson (1985) have concerned themselves with a particular problem or a specific technique. Many have considered basic topics or introductory courses, often spending a considerable amount of time to ensure a good understanding of the concepts on which mechanics is based.

The work on velocity done by Trowbridge and McDermott (1980) was taken further by Hewson (1985). He produced a computer program with an initial diagnostic stage, to identify the presence of the misconception, followed by a remedial stage to displace the misconception. The diagnostic stage included both of the velocity comparison tasks used in the original research and four others, represented on a computer simulation. From student reactions to these the programme could end or the remedial stage could be used, if needed. This aimed to demonstrate to students first that the fact that two objects having the same position does not indicate that their speeds are equal and secondly to provide them with a criterion for determining when velocities of two objects are equal. The program was found to be successful and this success was attributed to the fact that it started with the research into understanding of the concept, before trying to design a method to bring about conceptual change.

Minstrell (1982) described a method that he used to teach students about the forces acting on an object at rest. Initially he brought out into the open the preconceptions that the class had about this situation. From this starting point he was able to carry out demonstrations that would bring into question the certainty of the students original ideas. This approach demanded an environment in which

the students felt free to bring their ideas out for discussion and criticism. Eventually it was possible to draw from this situation the formulation of a concept, which could be agreed on by the whole group. In this way science does not dictate the laws that govern physical systems, but the students devise the laws for themselves, in a way that removes their misconceptions. This method takes up a great deal of time, but this can be justified by the fact that the identification of forces acting in a static situation was very important and could be extended when the students encountered dynamics. Terry, Jones and Hurford (1985) have also reported on a method designed to make students more aware of the forces acting on objects at rest. Their approach started with an object suspended from a spring where an upward force on the object was obvious and then moved in stages to an object resting on a table, where the forces are less obvious, but with the students aware that an upward force must be acting.

A similar approach has been recommended by Arons (1984), who advocates that concepts should be introduced first and then named later, to place emphasis on the concept itself rather than the terminology. He has also criticised the present techniques used for the teaching of science, (Arons, 1973), as these have failed to provide the majority of students with a real understanding of the subject, merely presenting them with a large quantity of knowledge to be learned in a short time. Very often higher order concepts have been taught while the foundations on which they rest have not been understood. Arons concludes that the way in which science is taught needs to be changed with a new approach adopted that will result in courses proceeding at sensible rates that allow the students time to gain an understanding of concepts and utilizing practical work in a way that helps to improve student understanding.

In Italy Borghi et al. (1987) have devised a new teaching strategy for topics in mechanics, which has been tried out in the teaching of trajectory motion. This

strategy consists of four stages, firstly an introduction to the topic using practical work, followed by viewing film or video that illustrates further practical work, then running computer simulations of these experiments and finally further practical work to reinforce the concept.

At the University of Leeds a group has produced a kit containing several mechanics experiments that have been designed for use by mechanics students. Williams (1985) has described two pieces of equipment that were initially tested, an inclined plane for the study of friction and a loop the loop model car track. It was felt that this use of equipment would increase the interest and motivation of the students, while demonstrating concepts without the complications that real life situations can bring. Trials with this simple equipment indicated that students found it stimulating and also that it provoked discussion about the concepts and the assumptions made in the models that described them.

The Mathematics in the Everyday World (MEW) Group (1989) has produced materials that focus on the students understanding of key concepts and relating mechanics to real situations. Their "What Happens If ?" questions are designed to challenge students understanding of the key mechanics concepts. These questions take very simple situations and ask the students to describe what will happen. Many of the problems posed expose students to a realisation of the weaknesses of their approaches.

As a result of the research carried out at the University of Washington into student understanding of kinematics a new conceptual approach to the teaching of kinematics has been produced by McDermott et al. (1987). It concentrates on developing concepts and distinguishing between concepts that the research has shown are confused. It begins with instantaneous velocity, which is developed through two approaches, practical work and graphs of motions. Drawing

distinctions between concepts began with velocity and position and then moved on to deal with velocity, change of velocity and acceleration. Finally time is taken to study the relationships between graphs, concepts and motions. This was found to be a time consuming process, but it did produce a better understanding in the students of the concept involved. It was felt that spending this amount of time was justified because of the fundamental nature of the concepts under consideration.

A modelling approach to the teaching of mechanics was developed by Halloun and Hestenes (1987). As research had indicated the failure of traditional teaching methods, they developed a completely new course based on the teaching of modelling skills. It was hoped that this would not only contribute to the improved understanding of mechanics, but would also be beneficial in other areas of the students studies. The course was based on problem solving and aimed to challenge misconceptions. An experiment to compare the group following this course with a traditionally taught group, revealed that it was very successful. It was considered that an introductory course of this type that developed modelling and problem solving skills, could then be followed by more traditional lecture courses that built on this foundation. Thus a modelling course of this nature would be an ideal way to prepare students for their future studies.

Another new introductory mechanics course was designed by Hake (1987) at Indiana University. Its aim was to encourage students to gain a Newtonian understanding of mechanics. The course utilized "Socratic" laboratory sessions that were designed to promote concept formation and challenge misconceptions. Many of the tasks used were chosen because they had been found to evoke a non-Newtonian response, so that the students would feel dissatisfied with their intuitive thoughts and begin to search for better explanations. In addition the

course lectures consisted mainly of teaching problem solving, class discussion of concepts, demonstrations and showing the "Mechanical Universe" videotapes. The use of the Halloun and Hestenes (1985a) mechanics diagnostic test demonstrated that there was a considerable improvement in student understanding of concepts for this course compared with students in similar establishments following more traditional courses. In addition to the students a group of non-physicist professors followed the course, and commented that they found the laboratory sessions and the video tapes particularly helpful. Although more work is needed to confirm the success of this type of teaching, the author felt confident that the approach taken in it had several advantages.

Findings from cognitive science, which is now becoming more concerned with mechanics teaching, have suggested new approaches to the teaching of mathematics and science. Resnick (1983) has outlined some of these and the reasons for them. Students seem to have been unable to apply the knowledge that they have gained in the classroom to real physical situations and have been very weak in the problem solving skills required in the real world. To improve this state of affairs teaching needs to cultivate the skills and processes needed in the real world. Three suggestions are made to help remedy this problem, starting to teach about concepts at an early age before the formation of preconceptions, paying more attention to qualitative understanding and challenging misconceptions.

A common feature of all these new approaches, highlighted by Resnick (1983), is that they attempt to challenge students' misconceptions. Some specifically challenge these misconceptions, before beginning a course of instruction while others have developed courses that involve the challenging of misconceptions.

2.5 The Use of Video in the Teaching of Mechanics

The argument that video can be of benefit to students has been put forward in many instances, and in particular for those on science and mechanics courses. Hake (1987) has used a considerable video element in his introductory mechanics course, the Open University (OU) has a large stock of video materials, while others such as Borghi (1987) and Whitaker (1983) have used small amounts of video to illustrate experiments and motions in the classroom.

Aicken (1975) has put forward the argument that television and especially video can greatly enhance the teaching of science when used in a suitable manner, but can also remove motivation and be found boring by the students. The pressures of examinations seem to have diverted school science away from the making of discoveries and solving problems to the learning of what appears to be boring and irrelevant facts, removing the excitement of studying science in schools. However the responses to some of the popular scientific television programmes indicate that there is still a great public interest in science and a desire to learn about it. Television has the potential to provide great motivation and stimulation for pupils if used correctly. Most of the school science programmes have submitted to the same pressures of the examinations, rather than following the more stimulating lead of the popular programmes. The programmes should aim to stimulate thought by not being well packaged teaching units with conclusions that leave nothing to be discovered, but by being open-ended, leaving tasks for the viewers, so that they can go away and make their own discoveries. Producers of these programmes need to be aware of this and be less enthusiastic about trying to tie up all the loose ends in the programme. Television producers need to orientate themselves towards creating programmes that promote scientific thought rather than ineffectively take over lessons.

Video has a potential for use in the teaching of mathematics and particularly in mechanics. Although many subject areas have had extensive resources for some time, it is only recently with the advent of the video recorder that materials for teaching mechanics at sixth form level have become readily available. Berry and Huntley (1986) identified the main source of video resources for mathematics as the OU course broadcasts, that can be recorded off air, and cover a wide range of topics within mathematics. In addition to these a special package "Visualizing Mechanics" Berry et al. (1984) has been produced, using video adapted from OU programmes, for sixth form mathematics students.

Three arguments for using video in mathematics teaching have been developed by Berry and Huntley (1986). Firstly, that it can bring reality to the situations studied in mathematics not only making it easier for students to relate to concepts, but also increasing motivation by providing examples of the applications of the mathematics. New concepts can be explained and developed on video in ways that are clearer and more precise than are possible on any blackboard or other visual aid. Finally when skills have to be practised it can provide solutions for students as and when they are needed. New developments in video technology offer many new exciting possibilities for extending the range of applications of video in all areas of mathematics, in the future.

Clearly there are many arguments for using video in the teaching of mechanics, but no evidence that it does actually improve student understanding. There is also a recognition that for video to be effective it must promote thought about the concepts, in order that the students examine their own understanding of the concepts under consideration.

2.6 The Use and Evaluation of Video

The evaluation of educational technologies has passed through five distinct stages, which have been outlined by Ely (1987). These stages were initially to establish that a new medium could teach as effectively as an existing one, secondly to show how well it could teach, thirdly to see how well it could teach under different conditions and fourthly how it could help students of different abilities before recently using more sophisticated investigations incorporating all these factors. The style of research has also changed from being very quantitative to a much more qualitative style. Ely speculates as to how research will change in the future, to take more consideration of individuals and the way in which they learn, stressing that it will focus on why a particular medium is a successful teaching tool or not.

In the particular case of educational television much of the early research work has been summarised by Chu and Schramm (1967). This comprehensive work starts from the conclusions of research that have indicated that television is an effective educational medium and begins to look at the factors that influence learning from television. These factors include technical, production and instructional variables, with conclusions drawn after a discussion of the relevant research.

The nature of evaluation of educational media has been discussed by Bates (1981), who has indicated the direction in which he feels it should move. Traditionally evaluation has followed very set patterns, based on controlled experiments, that have frequently reported that there was no significant difference. There is a need for this type of research but it has often been used when inappropriate and not based on a theoretical framework. This is one of the reasons why producers have held such low opinions of research. Where involved

in production research should be able to give advice quickly, so that decisions can be made in time to be incorporated into the programmes. Helpful areas that have been ignored are student reactions and the cognitive processes involved. Bates feels that it is time to try to find research methods that will help to improve the understanding of how to make the best use of the media.

There is also a gulf between researchers and producers, with the result that either research is irrelevant or ignored by producers. Coldevin (1973) noted these difficulties and proposed a model for programme production that involved both the producer and the researcher, in an integrated approach to both production and research. Where the research is geared towards the needs of the producers in this way, the end product should be significantly better.

Ives (1971) put forward the recommendation that the evaluation of television and other such media should concentrate on the performance of test items rather than that of individual students. Rather than having a control group Ives would allow all the students to use the new media and then assess which aspects of its aims had been fulfilled most successfully. A score would be assigned to each question for this purpose instead of to each student. Clearly this approach could be used with a group of questions rather than individual ones if appropriate.

The importance of formative research has been stressed by Mielke and Chen (1983), when they described the research that was carried out for a series of children's science programmes. This research work was used in four areas, initially assessment of needs and development of format before evaluation of trial programmes and for offering advice during production. As a result of this child centred research they were able to develop a style that was both educational and appealing to the intended audience. Salkeld (1982) commented on the importance of the testing of trial programmes for the BBC computer

literacy project, which brought about a major change in presentation style. Thus it becomes apparent that evaluation and research have a vital role in the production of successful video and television programmes.

An example of a different approach to evaluation is described by Moss (1973) where students were asked to evaluate videotapes, in addition to more conventional achievement tests. The student evaluation was based on scales that rated some aspect of the programme, including both technical and production variables. Initially two scales were given and a third provided for the students own choice of factor. Eventually all three scales were left for the students' own choices, being successfully used in the majority of cases. From the combined results it was possible to identify five different types of learners, noting their difficulties and their concerns about the learning process. This evaluation helped to train students to use the materials more critically, diagnosed faults and strengths in the production and the ability of students to use it. They also involved students in suggesting improvements to the video and the way it was used.

Teacher assessment of broadcast materials has been used extensively in Hong Kong as a part of their evaluation programme. Haye (1973) has discussed this process, including reporting on the role of teachers in this evaluation. For every broadcast that is used the teacher is required to return a short questionnaire containing details of use and to rate the quality of the teaching, support material and presentation. It is also considered that some form of pupil evaluation would be a useful addition in the future.

The more traditional evaluative studies of the effectiveness of video or broadcasts have often been based on a controlled experiment and a statistical analysis. For example James (1970) compared the efficiency of a programmed

learning booklet and a video tape for teaching students to use a desk calculator. The evaluation utilized testing both immediately after the course and again a few weeks later. The statistical analysis revealed that there was no significant difference between the two groups, except with the division section when the control group was better. A questionnaire indicated that the students preferred the video course, but found the division section confusing. From this information it was obvious that this part of the video was unsatisfactory and eventually had to be remade.

Kempa and Palmer (1974) used video to teach practical skills in chemistry. The experiment used three groups, one with written instructions only, one with a video demonstration only and one with both. The evaluation consisted of a written test and an assessment of practical skills. There was no significant difference between the groups on the written test but for the practical work the video groups were significantly better, confirming as expected that it is easier to learn practical skills from a demonstration.

This type of research has concerned itself with video or television that is designed for a specific purpose with improved instruction as one of its aims. Other projects have evaluated the use of recordings of ordinary lectures or classes for students who are unable to attend the institution itself. At Aston University an extensive programme of this type, described by Fleetwood-Walker and Fletcher-Campbell (1985), has been developed and is about to undergo evaluation. A similar project was tried out at the North Carolina State University, to meet the demands of distance students. A small scale evaluation of the use of video tapes in this way, revealed that there was no difference between the attainment of the video and the live audiences, although the video audience felt that they would have learned more from a live lecture. In both

these examples the availability of video copies of lectures in the libraries was greatly appreciated by the full time students.

It is not only the content of a video programme, but also the way in which they are used that is an important factor contributing to their success or failure. Guide-lines for the use of video in the classroom have been set out on several occasions, for example by Koranyi (1984). In a paper on language teaching with video, she describes the advantages of video over other media before clearly explaining how to exploit a video programme. Preparation and follow up activities are strongly recommended, along with using the video in short sections that can be repeated after pauses for discussion. Before playing the video she suggests that tasks or questions are set for the students to consider while watching it. During the playing of the tape the teachers attitude can be important and he should also participate in the viewing. Careful use of video is needed to ensure that it is an active and not a passive experience.

The argument between using broadcasts or video recordings now seems to have faded into the past with the advent of many more video-recorders. However there is not just the greater convenience of the video recorder, but also the fact that they can be used in a way that will create greater enhancement of the learning process. Brown (1984) has discussed the arguments for and against the use of video-cassettes at the OU, many of these being financial or organisational, but also concerned with the educational value. The video-cassette offers the opportunity for interruptions and pauses during viewing, replaying of short or long sections, thereby giving the control of the learning process to the students themselves. OU students who have used video-cassettes rather than broadcasts reported that they found them significantly more helpful, and that they had contributed to improving their understanding. They also offer the possibility of

low level interactive video, which would have been totally impossible with traditional broadcasts.

An example of a low level interactive video of this nature is the OU video-cassette "Mathematical models and Fluid Mechanics" (OU(1984)). Parts of this video consist of demonstrations of experiments during which the student is required to take measurements and then use these in calculations, before the video proceeds. The advantages, for the teaching of mathematics, of this type of approach and video in general are described by Berry (1985) and illustrated with examples from the above video. The video can provide students with a realistic introduction to a topic, allowing them to get a feel for the subject matter and familiarise themselves with it before any mathematics takes place. The understanding of the physical meanings of mathematical concepts can also be greatly aided by the use of video to illustrate them. In the specific case of mathematical modelling, the process can be greatly enhanced by the use of video, both in the initial formulation and in the final validation stages, when the model is compared with reality. All these advantages of video can be incorporated into a complete package as in the case of the video described.

This low level interactivity is one of a few of the recent developments in video. Moss (1983) has pointed out the potential that video has to offer for all the diverse aspects of modern education. It makes possible a change in the way we educate, from the fairly ineffective styles traditionally used, to reorientating the learning process towards the student. As more and more video recorders become available in the home and in educational establishments, the opportunities for the exploitation of video in education extend. Not only does this make education more accessible but it opens up new ways of using the video, such as the low level interactive one described above. In the present climate of rapid social and economic changes the demand for continuing education is always growing, and

video has established itself as excellent medium on which to provide this. But despite this potential many educational television programmes and video resources have not been fully exploited, mainly because of a lack of communications between teachers and producers. Programmes that have been well researched, often because they cover sensitive issues, have generally had much more success.

Involving the students in the video is essential if the maximum learning is to result. Clay (1974) has reported on his findings about how student participation helps to improve learning from television. In controlled experiments he was able to identify significantly better recall in the students who had taken part in further activities after the programme.

Although it is quite clear that the way in which video is used has an effect on its value, many schools are still not making good use of it, and in particular are not incorporating it into a unified teaching strategy. MacIntyre (1985) has noted this and reported that for this reason a group of teacher training colleges have joined together to produce a series of videotapes, aimed at improving teacher awareness of the most effective methods of utilizing television and video. In-service training in the use of broadcasts and video has already proved valuable, and resulted in its improved use.

A study by Hurst (1981) has looked at the reasons why some teachers make such limited use of video-recordings and broadcasts. He identified as the main reasons for this some technical problems (probably no longer significant), that teachers often feel that they can do better than the broadcasts, and that they feel it is bad to use too much television or video. A programme needs to be outstanding to attract a large amount of use in schools. Much of this situation is

due to the lack of communication between teachers and producers, who are working to some degree in ignorance of each other and their expectations.

Thus it can be seen that the evaluation of video can be based on a statistical analysis of a controlled experiment, but it is important that the reactions of teachers and pupils are also considered. A video may produce a statistically significant improvement in learning, but unless it is welcomed and used in the classroom it has no real value. Evaluation should not be an academic exercise, but should enable teachers to make decisions about the suitability of the resources and help producers to identify the demands for video and the best methods of meeting them.

2.7 The Potential of Interactive Video

Interactive video is the most exciting development of educational video in recent years. This is a video recording either on tape or video-disc that in some way interacts with its viewers during play-back, possibly in a very simple way as described by Berry (1985). However there are very advanced systems, in which a computer can be linked with video player to produce an extremely complex educator, controlling a large bank of resources and options that it can tailor to the users requirements. At present there are many different ideas about the best type of hardware to use for interactive video, which has resulted in the design and production of a huge variety of systems, most of which are incompatible.

A typical interactive video system first shows a sequence of video to make a teaching point, which is then tested by the interactive element of the system that poses a question for the student. Depending on the response the programme can move to the next section or present a remedial section to reinforce the previous teaching. Alternatively the interactive video may initially create a situation, and

a decision that has to be made. The users' response can then be interpreted by a demonstration of the outcome of his choice.

Clark (1984) has described the advantages interactive video-discs have over traditional forms of education. That the learning process needs to be active and not passive is in no doubt, involving exchanges of ideas and leading students to an understanding of the topic. Teachers can offer this, but other traditional media such as books, film or linear video do not, also associated with the last two of these is the problem that the learner cannot control his rate of progress. The computer has demonstrated its ability to be interactive, but has lacked the storage space needed and the illustrative power of video. A combination of a video-disc and a computer can provide the interactivity with the advantages of being able to provide more vivid video images and storing a vast quantity of information on the video-disc.

Doulton (1984) observed that it is in the training of employees in their workplace that some of the advantages of interactive video are really exploited. It can bring to training all the advantages outlined above, but its flexibility means that it can be used almost anywhere at any time, and make considerable financial savings for the companies involved. The realism that it brings to these training situations is invaluable, especially when decision making is involved, as it allows the trainees to see the consequences of their actions.

A three tiered scale has been defined for levels of interactive video which indicates the different levels at which interactive video can be used. These have been explained by Parsloe (1983), the lowest level simply being a video that allows the student to control its use, via the recorder itself, but that does not respond to the user. An example of the use of linear video adapted for this use in mathematics teaching has been described in section 2.6. The middle level

allows the student to respond to multiple choice questions and can provide alternatives as a result of these responses. For the highest level a computer is used in conjunction with the video player, which means that the range of possibilities is almost unlimited. A fourth level has been suggested by Priestman (1983) to allow for future developments that he feels will eventually take place.

One of the major problems with interactive video at the moment is the range of different incompatible systems, some based on disc and others on tape. Duke (1983) only saw tape as a short term development before disc took over completely, as tape systems had many limitations in comparison with discs. However there does still seem to be considerable enthusiasm for tape systems. Priestman (1983) has highlighted some of the advantages of videotape over video-disc. These being more concerned with the practical side of production, as tape is cheaper and easier to produce, easy to update and modify and can utilize existing stocks of video materials.

One tape based system that has been developed by BP for use in their staff training programmes is CAVIS. Copeland (1983) has described this system in some detail, referring to the fact that it has been designed to mix presentation styles and be easy to use, both for the trainee and the course-ware designer. It is also very flexible in these respects allowing students to move to any section of the programme at any time and its VHS format permitting the use of existing video materials. Incorporated in the programmes is a monitoring and evaluation system, which can identify both student and course-ware deficiencies.

Roach (1984) has reported on experiments with interactive video carried out at University College, Cardiff. Beginning with a tape based system and continuing with the production of a pilot video-disc. The tape system clearly demonstrated both the potential of interactive video and the drawbacks of the particular

system. A pilot interactive video-disc was then produced covering four different subject areas, which provided the team with many insights into the processes of planning and production. Plans for some evaluation of the disc were made along with some ideas for future developments.

O'Neill (1987) has identified three criteria that interactive video satisfies and account for the current enthusiasm for it. Firstly that when a learner is actively involved then the learning is most effective. Controlling his own rate of progress, leads the student to be more motivated. Finally that if the learning process reflects the real world then the subject matter becomes more relevant and stimulating.

The potential of interactive video-disc to become a widespread new medium in schools was assessed by Chambers (1987). The quality of the pictures does not match that of traditional film, but accessibility and flexibility of them offers many advantages. More crucial is the commercial viability of the video-disc, as it is very expensive to produce and requires large sales to recoup the initial outlay, which are unlikely to materialise until more schools have the necessary hardware. However the hardware is also very expensive and few schools are likely to be willing to invest this amount of capital until a greater range of video-discs become available. Thus it appears that unless outside aid is forthcoming, interactive video-disc technology is unlikely to establish itself in schools in the near future.

However since Chamber's assessment, two IV projects have been sponsored and found their way into British schools. Both of these projects have included aspects of mathematics as well as other curriculum areas. The first of these was the Interactive Video in Schools Project (IVIS) funded by the Department of Trade and Industry. It consists of eight projects each associated with different

areas of the secondary curriculum, being produced and tested by project teams. The mathematics component of IVIS was a video-disc described by Kennett (1988), produced and tested by the University of Exeter. This package was based on a situation where students are required to organise a school disco. The second of these projects was the Interactive Learning Project based at Newcastle University. It was sponsored by the nuclear industry and included a mathematics section on probability. So there is evidence of IV systems appearing in British schools, through these schemes and a variety of resources developed for use on them. Both of these schemes are also examining the classroom management of IV.

IV is a fast growing new technology that despite its expense is finding its way into schools. In America, Systems Impact Inc. are marketing a range of IV packages that deal with the core concepts of mathematics. In time if these early projects are successful and found to be effective in the classroom, then there will be more interest in the development of further IV resources, which will in turn promote more interest in IV. If IV is to become an important medium in mechanics then funding will have to be found to provide for the initial production of suitable resources.

CHAPTER 3 - REVIEW OF THE VIDEO RESOURCES FOR TEACHING MECHANICS

3.1 Introduction

At an early stage of the research it was essential to identify the potential video resources that could be used in the project and to assess their suitability for sixth form students. The review was based on searches of the catalogues produced by the British National Film Institute (BNFI)(1963-1990) as well as the catalogues and publicity materials of various film libraries and suppliers. The results of this review are described briefly in this chapter, but the complete review has been included as appendix A. This review had an important role to play in the development of the teaching package that is described in section 4.3.

The video resources that were identified as being of potential interest to teachers of mechanics originated from three main sources, which are each described below.

(i) A large proportion of the video materials that were identified and are currently available, have been produced by the OU. In the main these consist of the broadcasts that are part of the OU's courses, but also include the "Visualizing Mechanics" package by Berry et. al. (1984).

(ii) Resources previously available on film can now be obtained on video cassettes. Much of this material is now quite old and appears very dated, but some does exist that is very suitable for use in the teaching of mechanics concepts.

(iii) There has been a small number of video resources produced recently which generally take very modern approaches to their presentation which in most cases are more in line with the broadcast television that students experience out of school. Some of these new productions have been closely linked with the development of new A-level courses and are aimed specifically at sixth form students.

Each of these areas is examined individually and conclusions presented about the provision of video resources for mechanics teaching.

3.2 Open University Programmes

The OU television programmes are usually broadcast once each year and a licence to record them on to video cassettes is available, thus providing a resource that is easily accessible for all teachers. Table 1 summarizes the visual material relevant to a first course on mechanics, broadcast by the BBC for the Open University.

Each of these programmes is designed to fit into a standard sized broadcast slot and so they all have a length of 25 minutes. This is probably not an ideal length of programme for classroom use, but many of the programmes can be used in part. The following three sub-sections describe the resources that are listed in Table 1.

Course	Title	Content
MST204/04	"Newton's Equation of Motion"	Newton's 1st and 2nd laws.
MST204/07	"The Fabulous Perfect Spring"	Simple harmonic motion.
MST204/08	"Off the Record: Resonance and Damping"	Forced and damped oscillations.
MST204/17	"Projectiles - Motion in More Than One Dimension"	The analysis of the path of a shot putt and the optimum angle for launching.
MST204/30	"Newton's Third Law"	Newton's 3rd law, centres of mass and conservation of momentum.
S101/03	"Motion - Newton's Laws"	Newton's three laws and conservation of momentum.
S271/02	"Acceleration at Constant Speed"	Circular motion.
S271/03	"Energy to go Round"	Kinetic energy of a rotating object, moment of inertia, and design of flywheels.
S271/06	"Juggling With Physics"	Most topics met in mechanics courses.
T232/02	"Free Body Diagrams"	Free body diagrams, forces in equilibrium, friction, moments and problem solving.
T232/04	"Dynamic Analysis"	Demonstration of the solution of two engineering problems.
T232/06	"Work, Energy, Power"	Work, energy, power and application of these to flywheels.
T281/01	"Motion and Newton's Laws"	Motion of the centre of mass and reaction forces.

Table 1 - Summary of Content of OU Programmes

3.2.1 Mathematics Programmes

The OU television programmes from the MST204 course provide a rich source of material. This is a course in mathematical models and methods, which utilizes several examples from the field of mechanics. The emphasis of these

programmes is on the setting up of models, making predictions from them and verifying these results in experiments and demonstrations. The approach taken in these programmes is very much presenter based and the slow pace reflects their original purpose as distance learning materials. As these programmes were produced in 1980, they do now show some signs of age, which is particularly reflected in the appearance of the presenters.

The first of these "Newton's Equation of Motion" (OU(1982a)) explores Newton's first and second laws which after a discussion of the history of the development of the study of motion, gives students a chance to compare their understanding of motion with various historical ideas. This in conjunction with the practical demonstrations illustrating the relationship between force, mass and acceleration provides an introduction to Newton's laws.

Simple harmonic motion is covered by "The Fabulous Perfect Spring" (OU(1982b)), a programme which examines the motion of an idealised spring. Equations of motion are derived initially by considering the forces involved and then from an alternative approach considering energy. Animations and experiments are used to support the theory as it is developed, and to illustrate the characteristic properties of simple harmonic motion. This theme is extended, in "Off The Record : Resonance and Damping" (OU(1982c)), to the study of forced and damped oscillations, that would be suitable for use with students of Further Mathematics.

"Projectiles - Motion In More than One Dimension" (OU(1982d)) is based on an investigation of the motion of a shot putt. The study is introduced while watching shot putters in action, then a sloping air table is used to simulate the path of a shot in slow motion and to confirm predictions made from the mathematical model that was developed. In particular the model is used to

determine the optimum angle of projection of the shot, to reach the maximum range.

The study of mechanics, relevant to sixth form students, in this course is concluded with the programme "Newton's Third Law" (OU(1982e)), which considers the motion of systems of particles, emphasising the importance of the centre of mass. The concept of conservation of momentum is also considered, with predictions from it being verified in experiments. As in the programme on Newton's first and second laws, practical demonstrations to support and illustrate the theory play a vital role.

The M101 course on mathematical modelling also includes one programme that contains a significant mechanics element. "Modelling Cranes" (OU(1978a)) applies a modelling process that has been developed in earlier programmes to analyse the forces present in a simple crane. The main thrust of this programme is on the use of vectors to represent forces when modelling, but it does present an interesting application.

3.2.2 Science Programmes

Television programmes from the OU science courses S101 and S271 provide resources very suitable for use with A-level students. As with all the OU productions they are based on a presenter, but do concentrate on the concepts under consideration, with examples of the applications of these concepts.

From S101 "Motion - Newton's Laws" (OU(1978b)) gives an introduction to these laws by studying motion on an ice skating rink and in space, where the complicating effects of friction and gravity can be ignored. All three laws are

demonstrated in these situations, and the principle of conservation of momentum is also discussed.

The S271 course includes two programmes concerned with circular and rotational motion. "Acceleration at Constant Speed" (OU(1983a)) studies circular motion, by first demonstrating the presence of an acceleration towards the centre of a circular path, and then derives an expression for its magnitude. It concludes by showing the consequences of removing the force causing the acceleration. The kinetic energy of a rotating body is considered in "Energy To Go Round" (OU(1983b)). This programme develops the concept of moment of inertia, and is well illustrated with examples of the use of flywheels. Also from S271 comes "Juggling With Physics" (OU(1983c)) which is based on a visit to the circus. Many situations are encountered here that involve the concepts which students should be familiar with.

3.2.3 Technology Programmes

The technology courses from the OU include some television programmes that contain exceptionally good examples of applications of mechanics, as part of the T232 and T281 courses. The emphasis of these programmes is initially on the explanation of techniques and concepts before developing them to provide examples of their applications in real world situations.

From the T281 course, "Motion and Newton's Laws" (OU(1983d)) demonstrates how the motion of complex systems can be modelled using Newton's laws, when the centre of mass is used to simplify the system. Trampolienists and athletes are used as examples of systems that can be modelled by a single point mass, even when the centre of mass is not necessarily in a fixed position within the moving system.

T232 contains three very good programmes for mechanics students. Forces in equilibrium are considered in "Free Body Diagrams" (OU(1979)), which begins with very simple examples and develops them to solve more difficult real problems. A pin jointed structure supporting a load illustrates an application of free body diagrams, with an analysis to find the forces acting on a joint in the structure. The programme "Dynamic Analysis" (OU(1980)) sets two engineering problems, first to find the minimum safe rate of rotation for a fairground ride and, second, the calculation of the forces acting on a gudgeon pin in a combustion engine. These two real problems are solved by applying the laws of mechanics, and a sequence of problem solving steps, that are laid out in the programme. These problems are well within the grasp of A-level students. "Work, Energy, Power" (OU(1981)) introduces these three concepts, develops the relationships between them and illustrates them with practical demonstrations. A description of the use of industrial flywheels as a store of energy provides the programme with examples to which these concepts can be applied.

3.3 Visualizing Mechanics

"Visualizing Mechanics" by Berry et al. (1983) was until recently the only resource that is available on video-cassette and designed for classroom use with A-level students. It comes with a booklet containing a programme synopsis as well as pre and post viewing exercises for each of the ten modules. The majority of this package is based on the OU MST204 broadcasts that have been described above, utilizing the broadcasts on Newton's laws, simple harmonic motion and projectiles. These are broken down into eight shorter modules that are more suitable for A-level students, with lengths of between seven and fifteen minutes. Two additional modules "Addition of vectors" and "Components of a Vector",

taken from the OU course MS283, are included to complete the package. The first of these looks at how forces and spin can be combined by the triangle addition rule and modelled by vectors; while the second describes how forces can be resolved into perpendicular components and applies this technique to solve a problem, where only the vertical components of the forces need to be considered.

The supporting booklet makes use of preparation and follow up materials including discussion sheets and worksheets containing exercises for students.

3.4 Older Resources

Before the use of video and television as a teaching aid, 16mm film was available and there were some programmes on areas of mechanics. However the film hire and setting up of the equipment were often time consuming, tedious activities which discouraged the use of film in the day to day teaching of a subject. Film materials can now often be obtained on video-cassette, at much lower prices than the original film copies. Some of these films, in spite of their age, are still worth consideration, while others appear so dated that they are totally unsuitable. Many of these films were originally aimed at secondary school pupils, with their emphasis on the nature of the concepts rather than any complicated theory. A number of films produced in Japan, but with English sound-tracks, illustrate some of these basic concepts very clearly.

One film particularly worth mentioning is "Action and Reaction" produced by Iwamani (1970), which develops the ideas of Newton's third law, and would be ideal for use with A-level students. Experiments with springs first demonstrate the presence of reaction forces, and then an optical technique is used to give a

clear image of the equality and opposition of these action-reaction forces involved when one piece of plastic pushes against another.

Another old film that also still has some potential is "What is a Force ?" produced by Coronet Instructional Films (1973). This film builds up a definition of a force as something that causes a change to the motion of an object. It then develops the concept of equilibrium by studying situations where more than one force is acting and discussing whether or not the motion is changing.

3.5 Recent Productions

Video production is a continuing process and modern resources are still being produced. There were two videos that were available at the beginning of the project and five others that became available while the research was in progress, three of which were developed as part of the research.

There were two modern videos, that were available at the outset of the project. The first of these was "Newton and the Shuttle", produced by BBC Television (1986). This takes the form of a case study where a space shuttle mission is described. Throughout the video the motion of the shuttle is used to illustrate Newton's laws and to demonstrate the importance of a good understanding of them. The second video was "Gravity, Weight and Weightlessness", produced by Bailey Film Associates (1985). This is a revised version of a film that was originally produced in the 1970's. It attempts to answer in a very thought provoking way the question "What is Weightlessness ?". Throughout it provides interesting examples, including several from orbiting spacecraft.

The video "Mechanics in Action" was produced by the Mechanics in Action Project (MAP)(1990). This video is aimed at students contemplating A-level

mathematics courses involving mechanics. It provides a fast moving sequence of examples of applications of mechanics many of which are taken from the Alton Towers amusement park. It also looks at Newton's laws and shows how these superseded Aristotle's ideas.

Another new resource is "Accident Investigation" produced by Aston University (1990). It follows a police investigation into a fatal road traffic accident, illustrating how the principles of mechanics were used in this investigation. Its format is very heavily presenter based and it has a very slow pace, which detracts from the otherwise potentially very interesting storyline.

All the other resources that have been produced were by the Centre for Teaching Mechanics (CTM) for the SMP's new Mathematics 16-19 A-level course. The first of these videos produced by the CTM (1988) was "Introduction To Momentum", a pilot that was used on a very small scale only. The other two were "Motion" CTM (1989a) and "Momentum and Collisions" CTM (1989b), which were used on a much wider scale. These two videos will also be the subject of further revision before they become widely available. These videos form an intrinsic part of this research project, as they were developed and produced in the light of the early findings of this research, and are dealt with in full in chapter 6.

3.6 Resources Needed

The OU is at present the primary source of visual materials for mechanics teaching, but other sources are now producing video aimed specifically at the A-level market. The "Mechanical Universe", is a set of videotapes, from an unidentified source, that were used in research and recommended by Hake (1987) in the U.S.A.. Unfortunately these tapes are not available in Britain, but

would provide a valuable extension to the existing range of resources if they were to become available.

Although a good range of visual material does exist there are some large areas of mechanics with little or no coverage, notably kinematics, momentum and energy, while other areas, such as Newton's first and second laws are dealt with on several different videos. Obviously there is a need for a more balanced range of video materials, as well as for video specifically designed for a-level students. There is no getting away from the fact that much of the existing video was not designed for A-level students and as such has disadvantages that were not envisaged by the original producers, particularly with regard to the style of presentation but also in the level and content. A number of videos produced specifically to provide a balanced coverage of the mechanics encountered in A-level mathematics courses would be of great benefit to both students and teachers alike. The initiatives being taken by CTM and MAP begin to meet this need, but there is still a great deal of ground to be covered.

3.7 Conclusion

The video resources described here are all easily accessible for teachers. The cost of the "Visualizing Mechanics" package is very reasonable and well within the budget of a school mathematics department.

Although the provision of video for mechanics at A-level is not perfect, a substantial part of the mechanics taught is served. If the available programmes are used in teaching they should be able to bring more interest and understanding to those studying mechanics. They will not however stand alone and need to be incorporated into a complete approach to teaching mechanics, where their potential can be fully exploited. This would include traditional teaching,

problem solving and practical work as appropriate as well as utilizing the flexibility of the video-recorder.

CHAPTER 4 - THE DESIGN OF THE EXPERIMENT

4.1 Introduction

Before discussing the detailed aspects of the evaluation and the methods used it is important to examine the motives for the study. These will identify why the measures used were selected and explain the general approach to the evaluation. It is important to understand both why mechanics is a subject of interest and why video could help.

Mechanics has been an area of concern to mathematics and physics educators for some time. Extensive research has been carried out, almost exclusively by physicists, revealing that students have great difficulty understanding the concepts and relationships of mechanics. Details of much of this research can be found in Chapter 2. In particular the taxonomy prepared by Halloun and Hestenes (1985b) has shown the range of misconceptions held by students within the subject area of mechanics. Further the research of Gunstone (1987) and Peters (1982) indicates that misconceptions are a very widespread problem and even exist in very able students.

Not only has mechanics been found difficult to understand, but it has not been popular with mathematics students. Research into attitudes by Stoodley (1979) revealed a hardening of students' attitudes to applied mathematics as they progressed through their A-level courses.

In the light of this type of research many efforts have been made to improve the teaching of mechanics, with views to improving student understanding and

attitudes to the subject. One approach that has been tried in a number of cases is video. Borghi et al. (1988) have used video as part of package that utilized practical work and computer simulations. Whitaker (1982) also made use of film-loops to provide concrete examples of motions. Berry (1985) has described how he feels that video can introduce real world problems, assist with their mathematical modelling and provide physical interpretations of mathematical theory. Although these and others have used video in mechanics, based on sound arguments that suggest it will help students and felt that its use has helped students, they have not produced evidence to support their claims that video improves learning.

Video was also used as part of a course developed by Hake (1987) at Indiana State University. This course was the subject of some evaluation that indicated that its students had a better understanding of mechanics upon completion than students following a similar course in a comparable institution. However video was only a single element of the approach taken in this course and could not be pin-pointed as a definite reason for the improvements, although the videos used were considered very favourably.

Thus although there is much speculation that video can help to improve understanding there is little or no research evidence to support these claims. The purpose of this study is to determine whether or not these claims are justified, by carrying out a carefully controlled experiment in which video is isolated as the major difference in the teaching approach.

Further by using an analysis, where possible, of the type suggested by Ives (1971) the videos that are most effective could be identified. Student and teacher reactions to the video tapes will also be sought in order to identify what they feel constitutes a good video. This information will be of value to producers

developing materials for use in mechanics as it will provide a set of guide-lines they can use.

At present there are groups interested in the production of video materials for use in the teaching of mechanics. SMP in particular are very interested in using video as an integral part of their Mathematics 16-19 course. They have commissioned the production of a number of pilot videos for trial in their pilot schools. Video production is expensive and time consuming and needs to be based on research that has identified the best way of using video. Although general guide-lines for production exist, there are none that relate specifically to material on mechanics. Since the review of video materials in chapter three pointed to a need for more video resources for the teaching of mechanics, it is important that suggestions as to produce these resources successfully are made. Bates (1981) has stated that research should be conducted to identify the best use of a medium, particularly to provide information for producers.

The aims of this evaluation can be summarised as the following statements.

- (i) To determine whether the use of video in the teaching of mechanics can improve student understanding of the concepts and relationships that make up mechanics.
- (ii) To draw up a set of guide-lines, for the production of videotapes on mechanics that will indicate the approaches that can promote motivation, interest and understanding.

This chapter sets out the approach that was taken and the details of the implementation of the evaluation.

4.2 The Design of the Experiment

The experiment was to consist basically of a comparison of the understanding of mechanics for a group or groups of A-level students working with video and a group or groups working without video. This would be carried out using tests to monitor student understanding of concepts as they worked through a series of topics which included video as part of their scheme of work. Additionally the experiment would use questionnaires to record student and teacher reactions to the videos used.

Before any detailed planning could be undertaken it was necessary to identify groups of students that could take part in the experiment. As the groups involved were to be compared there would be certain restrictions that would have to be placed on their composition and learning experiences, in order to ensure that the comparisons made were as credible as possible. Thus the first stage of the design, before any institutions were approached was to prepare a list of the factors that would need to be controlled in the experiment. It would then be possible to determine how well a particular school or college could meet these requirements.

It was decided that there were certain factors that could influence the outcome of the experiment and so restrictions to attempt to prevent this happening were imposed on the experiment. These factors and their associated restrictions are listed below.

(i) Academic Ability - It was essential that comparisons were made with students of similar ability. Groups would have to be formed with this in mind or checked to verify that this criterion was satisfied. In particular schools where students were set according to ability would not be suitable for the experiment.

(ii) Physics Teaching - Since the physics taught at A-level shares some common ground with the mechanics covered in mathematics, it is important that any effects of this teaching are considered. This factor would be difficult to eliminate but could be controlled by arranging for groups to contain approximately equal numbers of physics students.

(iii) Teachers - Every teacher is different, so it would be important to either use the same teacher for all the groups or to use them in such a way that any differences could be detected and controlled.

(iv) Teaching Styles - Different and even the same teachers may use different approaches or styles when dealing with the same topic with different groups. For this reason some control would have to be exercised over the teachers approaches to the topics.

(v) Institution - There were some reasons why it would be undesirable to work in more than one institution, such as lesson length, time allocated to subjects, catchment areas, teaching schemes, etc. It was therefore considered desirable, if possible, that the experiment should take place in a single institution. This would remove the problems that could be caused by comparing students in different institutions.

(vi) Syllabus / Scheme of Work - It was again essential that all the students involved were following the same scheme of work, as different schemes may place more emphasis on different topics.

(vii) Results of Tests of Understanding - These could well influence both the students and the teachers attitudes and approaches to mechanics, so the results would be withheld until the end of the experiment.

(viii) Sex of Students - This is a potentially controversial factor to consider, but by checking that the groups had similar male to female ratios it could be ignored.

In view of these factors an ideal experiment would be based on groups, from one institution both following the same scheme of work with the same teacher and split into control and experimental groups, that had been formed randomly from the available students. In practice it was far from easy to realise this situation. As local schools tended to have only one or two groups of A-level students, often set according to ability and taught because of timetable constraints by different teachers they did not seem to be suitable for the experiment. An additional problem was the reluctance of the schools to let different groups be seen to be treated differently. Thus it became clear that it was unrealistic to expect to be able to form true experimental and control groups. A quasi-experimental or non-equivalent design was therefore the only viable form for the experiment, based on existing teaching groups.

After some unfruitful enquiries had been made to local schools, colleges of further education were considered and a favourable response was received from Exeter College. The head of department and some members of the department were happy to become involved in the experiment. Initially it was anticipated that four groups of students and two teachers could be used, allowing each teacher to teach both an experimental and a control group. Unfortunately, due to staff allocation, this was not ultimately possible. However it became clear, during discussions with the college that if the extent of the experiment could be confined to the lower sixth topics, then there would be the possibility of working

with two consecutive year groups. This would allow the teachers to use the video with the first year group and not the second or vice versa. The final plan made use of four teachers in the first year, some of whom it was anticipated would be able to continue in the second year of the experiment. It was not certain if they would all be able to participate in the second year, but no definite decisions would be made until the summer term of 1989. If it were possible to repeat the experiment twice with the same teachers an analysis of variance that would remove this variation could be carried out.

It would not be possible to create groups randomly using the colleges' students. However, as the allocation of students to groups was as a result of many different factors, it was felt by the staff, based on their past experience, that the groups formed would be approximately equivalent. This would of course have to be verified at an early stage in the experiment.

Once an outline plan for the experiment had been agreed with the college and its staff, it was possible to begin to formulate a detailed approach to the experiment. This began with the development of the teaching package, described fully in section 4.3, which determined the videotapes that were to be used in the experiment and the supporting materials that would be needed. The package also provided guide-lines, for the teaching of both the experimental and the control groups, that would help to ensure that the effects of different teachers and teaching styles to the topics would be minimised.

Upon completion of the teaching package the next phase was the design of methods of assessment of the video. As outlined in section 4.1 these would cover two areas, student understanding of mechanics concepts and the impressions of both students and staff of the videos used. The development of these methods of assessment is described fully in Chapter 5.

Due to the quasi-experimental design of the experiment it was essential that evidence was provided to support the claim that the control and experimental groups were equivalent. This was to be done in two ways. Firstly a questionnaire was to be used to gain information about the students backgrounds and academic achievements. This would provide evidence that would indicate if the factors (i), (ii) or (viii) were likely to influence the experiment. Performance on sixteen plus examinations would be compared using statistical tests. Secondly a pre-test would be used to examine student understanding of concepts at the outset of the experiment. It was hoped that this test would indicate that there was no significant difference in the two groups understanding of the relevant mechanics concepts.

Post-tests would be required to measure the improvements in student understanding after the implementation of the teaching programme. The results of these would again be tested for statistical significance. As the progress of the groups through the scheme of work used at the college could not be predetermined precisely, it was anticipated that it would be unlikely that all the groups would study the same parts of the teaching package at the same time. Therefore a delayed post-test was to be used in all cases. It was anticipated that this type of testing would also give a stronger indication of whether or not any student misconceptions had been changed. The administration of the tests was timed at approximately four weeks after all the students had completed the relevant work from the teaching package. In some cases there would inevitably be complications as there would be times such as holidays and examination periods when the students would not be available.

Student and staff opinions and reactions to the videotapes were to be obtained by the use of questionnaires after watching the videotapes. Two different

questionnaires were used reflecting the differing ways in which students and staff would evaluate the videos.

Thus the experiment was based on a quasi-experimental design which checked that the groups were equivalent, ensured students followed the same scheme of work and attempted to rule out any differences that could be attributed to the teachers. This was the best design that could be obtained within the restrictions that were placed on the experiment, both in order to control it and to make it practical to undertake. The timetable for its implementation is given in Table 2.

Oct 88	Background questionnaire completed by students.
Jan 89	Pre-test taken by students.
Jan-Mar 89	Block 1 of teaching package used.
Apr 89	First post-test taken by students.
Apr-Jun 89	Block 2 of teaching package used.
Jul 89	Second post-test taken by students.
89/90	Repeat of above timetable for available students.

Table 2 - Initial Programme for the Implementation of the Experiment

4.3 Development and Design of the Teaching Package

If the videotapes that were available were to be used in an evaluation, it was important that they were properly presented and supported by suitable teaching materials. Further if comparisons were to be made between experimental and control groups it was essential that the materials were presented and used in a consistent manner. In order to meet these requirements the preparation of a comprehensive teaching package was essential and would form the basis of the teaching on which the use of video was to be based.

The preparation of the teaching package was designed to fulfil the educational aims listed below.

(i) To enable the teacher to use the videotapes effectively by briefing them on their contents and approach, suggesting how to follow them up, providing any extra information that may be needed and exercises for the students.

(ii) To take account of students existing conceptions of the concepts covered and attempt to remedy any predictable misconceptions whenever possible.

(iii) To provide a realistic rather than a theoretical environment in which to study mechanics, in order that the students may become aware of the assumptions made in modelling real situations, encounter some of the applications of mechanics and hence discover the relevance of their study.

(iv) To make the subject interesting and motivate students.

These aims were devised to take account of the needs identified by previous research into student understanding of mechanics. In addition there were more specific objectives associated with the content of each section of the teaching package.

The first stage in the development of the teaching package was the selection of the video materials to be used in the experiment. Once Exeter College had agreed to be the venue for the experiment this was a natural progression from the review of the video material. The review was used in conjunction with the syllabus for the college's A-level course to draw up a provisional plan, outlining the video materials that could be used in the experiment.

In this process there were a number of constraints that needed to be incorporated into the planning of the package to satisfy the design of the experiment. Firstly, in order to allow the experiment to be used with two different year groups, it was

necessary that all the video used related to topics that were likely to be covered in the first year of the students' study. Secondly it was hoped to cover as many topics as possible within this first year of study. Third, in order to make some comparisons about video materials, videos from several different sources were to be included. Finally the package had to provide as similar a learning experience for both the experimental and control groups as possible with the one exception of the video.

As a result of this process a proposal, that identified the video tapes to be used in the package, was drawn up. This proposal divided these videotapes into four topic areas, each covered by two or more tapes, along with a set of objectives associated with each tape. This proposal is outlined in Table 3. Around this outline and using the objectives for each section a first draft of the teaching package was prepared.

<p>BLOCK 1 - Forces and Vectors</p> <ol style="list-style-type: none"> 1. "What is a Force ?" 2. "Adding Vectors" 3. "Components of a Vector"
<p>BLOCK 2 - Newton's Laws and Momentum</p> <ol style="list-style-type: none"> 1. "Newton's First Law" 2. "$F=ma$: Newton's Second Law" 3. "Action and Reaction" 4. "Introduction to Momentum"
<p>BLOCK 3 - Projectiles</p> <ol style="list-style-type: none"> 1. "Path of a Projectile" 2. "The Optimum Angle"
<p>BLOCK 4 - Circular Motion</p> <ol style="list-style-type: none"> 1. "Acceleration at Constant Speed" 2. "Dynamic Analysis"

Table 3 - The Initial Proposal for the Content of the Teaching Package

Although the initial proposal for the content of the teaching package given in Table 3 was to change, the structure of each section within the package was to

remain basically unaltered. This structure consisted of a set of teachers notes, occasionally additional notes that could be used by either students or teachers and exercises for the students. The teachers notes were divided into four sections providing a summary of the video and its supporting material, notes for the teachers using the video, notes for the teachers not using the video and answers to the exercises.

The notes for the teachers using the video had two main purposes. There were often points about the video of which the teacher should be aware before using it, such as results and terminology with which the students may be unfamiliar. Additionally there were often other points arising from the video that needed to be explained before or after viewing, such as the explanation of results used or the discussion of topics raised. Finally there was often a need to link the material on the video to the exercises, by covering additional points or topics.

The notes for the teachers not using video were primarily designed to be used in conjunction with the summary of the video to outline the approach that they should take to the teaching of the topic. It is one of the important features of the design that the teaching of all the groups should be as similar as possible with the one exception of the video. These notes are provided to help the teachers maintain this similarity, by indicating an approach that is comparable to that used by the video. As with the other teaching notes they also identify key points that need to be covered before students attempt the exercises.

Additional notes were included with some of the sections where the results or ideas with which the teachers may be unfamiliar were used, for example Aristotle's ideas about motion. These were also provided when the videos did not explain results in detail and it was felt that a more comprehensive explanation

would be useful. These notes were prepared in such a form that they could be reproduced for students if required.

A set of student exercises was prepared for each module. Due to the design of the experiment it was important that both the video and the control groups should be able to use the same sets of exercises. For this reason no references were made to the videos in the exercises. Also the questions would make only references to topics that were covered by both the video and the control groups. The exercises were based on the following set of objectives which reflect the broader aims of the whole teaching package.

(i) The questions whenever possible would refer to realistic situations rather than idealised systems, thus allowing students to relate real situations to the theoretical models and consider some of the assumptions made in the model.

(ii) The exercises would pose questions that would help to reveal misconceptions, that had been identified by previous research, so that these could be dealt with.

(iii) The exercises would give the students opportunities to practise applying and exploring the concepts and relationships presented by the videos or by the teachers.

This draft version of the teaching package was then taken to Exeter College along with the relevant videotapes and was discussed with the staff that it was anticipated would be involved in the experiment. As some of them had already used some of the tapes their comments were particularly valuable. The bulk of the discussion centred on the video tapes and the way in which they could be

used. The discussion relating to each of the videotapes in the draft teaching package is outlined in Table 4.

Video	Teachers' Comments
"What is a Force ?"	This was new to the staff and was liked, but they felt that it would be more appropriate to use it when studying Newton's Laws.
"Adding Vectors"	This had been used by some of the staff. It was not popular and they felt that, although it could be used to extend the topic, it was not recommended for use.
"Components of a Vector"	This was disliked by the staff, although it did utilize some good models. Of particular concern was the fact that it did not show how to find the actual components. The staff felt that a better treatment could be given by the teacher.
"Newton's First Law"	This had been used before and the staff were happy to use it again.
" $F=ma$: Newton's Second Law"	This had been used by some staff, who felt that it was very long and tedious, but that part of it could be used if there was no better alternative.
"Action and Reaction"	This was new to the staff, who liked it and would be happy to use it.
"Introduction to Momentum"	This was again new to the staff who were pleased to see that new material was being produced, and were happy to use it.
"The Parabolic Path of a Projectile"	This had been used by the staff before, who were happy to use it again, although they did have some reservations about the presenters.
"The Optimum Angle"	This was another video that the staff had used and were prepared to use again.
"Acceleration at Constant Speed"	This was regularly used by one member of staff who found it very valuable.
"Dynamic Analysis"	This was new to all the staff, who liked it, particularly the introductory sequences. It was felt that details of the piston engine analysis would need to be available and that the follow up work should be restricted to vertical circular motion at constant speed.

Table 4 - Summary of the Discussion at Exeter College

As a result of this meeting the two videotapes on vectors were dropped and "What is a Force?" re-positioned to follow on from "Newton's First Law". Although the order of the remaining tapes was unaltered they were re-classified into two blocks that corresponded to the spring and summer terms of the first year of study, based on the teaching scheme prepared by the staff at the college. The new outline of the teaching package is given in Table 5. In addition to the major changes outlined above, several minor changes were made in the light of the teachers comments and as a result of my own reviewing of it, in particular after having worked through the exercises.

<p>BLOCK 1 - Forces and Newton's Laws (Spring Term)</p> <ol style="list-style-type: none"> 1. "Newton's First Law" 2. "What is a Force ?" 3. "$F=ma$: Newton's Second Law" 4. "Action and Reaction"
<p>BLOCK 2 - Momentum, projectiles and Circular Motion (Summer Term)</p> <ol style="list-style-type: none"> 1. "Introduction to Momentum" 2. "Parabolic Path of a Projectile" 3. "The Optimum Angle" 4. "Acceleration at Constant Speed" 5. "Dynamic Analysis"

Table 5 - Modified Proposal for the Teaching Package

At the initial planning stage a set of objectives for each section of the teaching package was prepared, in addition to the general aims of the whole package. These too were revised after the meeting at Exeter College. The final version of these objectives is listed below.

1. "Newton's First Law"

(i) Many students intuitively believe that a force acts in the direction of motion of any moving object. The main objective of this section is to challenge that

belief, by comparing Aristotle's and Newton's laws of motion and identifying the weaknesses of Aristotle's model.

(ii) Additionally to lead students to an understanding of Newton's first law, that objects move with constant velocity unless acted on by a net force.

2. "What is a Force ?"

(i) The main objective, which develops from Newton's first law is to provide a definition of a force, as something that causes a change to the motion of an object.

(ii) To allow students to identify forces.

(iii) Further to extend this idea to situations where more than one force is acting, particularly to being able to determine whether or not these forces are in equilibrium.

3. " $F=ma$: Newton's Second Law"

(i) To show that Newton's second law provides a model that agrees with reality, unlike Aristotle's model or some student's intuitive ideas.

(ii) To lead students to an understanding of Newton's second law when applied in one dimension, in particular being able to predict the motion that would result when a force is applied to an object with a certain mass.

(iii) That students should be able to make observations of motion and interpret these in terms of the forces that must be acting on the object.

4. "Action and Reaction"

(i) That students should be aware that whenever a force acts there is always a reaction force that is equal in magnitude but opposite in direction.

(ii) That these two forces are exerted by different bodies, i.e. that if A exerts a force on B then B exerts a reaction force on A.

(iii) That these forces are always equal in magnitude regardless of the mass of the objects involved or any motion that takes place.

5. "Introduction to Momentum"

(i) That momentum is the product of mass and velocity.

(ii) That students understand the role that momentum plays in determining how difficult it is to stop or start a motion.

(iii) That students are aware that momentum is a vector quantity and is therefore defined with a magnitude and a direction.

6. "The Parabolic Path of a Projectile"

(i) Students should understand that the path of a projectile is parabolic and that the horizontal and vertical components of the motion are independent.

(ii) Students should be able to identify the forces acting on a projectile at any instant in its flight.

(iii) From this students should be able to derive equations of motion for a projectile and hence calculate the range, time of flight and maximum height for the projectile.

7. "The Optimum Angle"

(i) Students should be aware that there are pairs of angles of projection that lead to the same range when the projectile is launched from ground level.

(ii) Further, be aware that the maximum range is achieved for a single angle of projection of 45 degrees.

(iii) Additionally students should recognise that this optimum angle of projection is not the same if the projectile is launched from a different height.

(iv) Students should be able to calculate the range of a projectile launched from any height.

8. "Acceleration at Constant Speed"

- (i) Students should understand that for circular motion at constant speed the acceleration of the object is directed towards the centre of the circle.
- (ii) Further that circular motion is only described if a force is present to provide this acceleration, and that if it is removed the object will leave the circle along a tangent.
- (iii) Students should be aware that the magnitude of the acceleration depends on the rate of rotation and the radius of the circle, in particular that its magnitude is given by v^2/r or rw^2 .

9. "Dynamic Analysis"

- (i) Students should understand that for motion in vertical circles the magnitude of the resultant force remains constant if the rate of rotation is constant.
- (ii) Further that there is a minimum rate of rotation below which circular cannot be described.

Once the preparation of the teaching package was complete it was duplicated and passed, along with the necessary video tapes, to the staff at Exeter College so that they would have time to familiarise themselves with it before using it in their teaching. A copy of the teaching package is included in appendix B.

4.4 The Implementation of the Experiment

In the lead up to the experiment there were no initial problems once the groups to be used in the experiment had been allocated by the college. The first set of background questionnaires were completed in October 1988 and the pre-test administered in January 1989. The first block of the teaching package was used during the spring term of 1989. However due to the timing of this teaching and the pressures of examinations at the end of the term it was not possible to

administer the first post-test until after the Easter holiday in April 1989. Thus the first post-test, which covered the forces content of the teaching package, was delayed considerably. During the course of the summer term it became clear that the new scheme of work proposed by the college was very optimistic in comparison with the progress of the actual teaching. The topics of momentum and projectile motion were completed during this term as anticipated but the circular motion section was delayed until after the summer holiday. For this reason it was necessary to conduct two further tests instead of one single one for the whole block as had been originally planned. The students' understanding of momentum and projectiles was tested during June 1989, again well after the actual teaching had taken place.

At the end of the summer term of 1989 a number of problems arose that would affect these groups for the remainder of the experiment. Firstly one of the members of staff involved in the experiment unexpectedly left the college at the end of the summer term. Her group was one of the video groups and was taken over by another teacher, who was also teaching one of the control groups. As he was familiar with the experiment this caused no administrative problems, although the continuity of teacher was destroyed. The second problem concerned the other video group. Due to the loss of students through the year, but particularly after the end of year examination, there was an amount of reorganisation of teaching groups. Unfortunately the second video group was amalgamated with another teaching group and lost from the experiment. Thus at the beginning of the Autumn term there was only one video group and two control groups available for the experiment. In spite of this set-back the topic of circular motion was covered. The topic was tested in January 1990, again with a delay after the topic had been taught, during the last few weeks of the Autumn term.

As timetables were prepared for the new intake at the college for September 1989, two teachers who would be prepared to take part in the experiment were both allocated two teaching groups. Thus it was possible for the experiment to be repeated for a second time, but now with the situation of two teachers that had initially been considered ideal. There were a few minor changes made to the content of the teaching package that are described in section 4.5, due to the removal of one video and the insertion of another new one that became available in the summer of 1989. Because this new video would be used in the first term of the students first year of study the background information questionnaire and the pre-test were administered at the same time in October 1989. The first post-test followed this in February 1990. This was a test after a considerable delay for the motion questions but a moderately short one for the forces topics.

As there was some reorganisation of the teaching order for topics in the light of the college's experience the previous year the section on projectiles was used at an early stage in the summer term and was therefore tested at a different time to the momentum, which was taught at the beginning of the autumn term. The projectiles questions were administered in May 1990, shortly after the teaching had been completed.

Two problems arose at the beginning of the autumn term of 1990. The first was a decision taken by the College to change their examination board and syllabus. This caused increased pressure on staff and the removal of the video "Dynamic Analysis", which was not relevant to the new syllabus. The second problem was due to the reorganisation of teaching groups. As in the previous year one group involved in the experiment was disbanded and the sizes of all the groups were reduced. In this case it was one of the control groups that was lost. Despite these losses the experiment continued with the topics of momentum and circular motion being covered in the autumn term. The tests for these two topics were

then administered at the end of the autumn term together, with a delay after they had been taught.

4.5 Modifications to the Teaching Package

The modifications that took place to the teaching package were for two reasons. Firstly the strong dissatisfaction of the teachers with the video "F=ma : Newton's Second Law". They had been initially unenthusiastic at the prospect of including this video and the poor reaction of the students to it during the first year added weight to the case for its removal from the teaching package. So for the second year of the experiment it was removed from the teaching package.

The second modification was due the availability of new video resources. These had been produced for SMP new Mathematics 16-19 course, by the CTM. Their design had taken place within constraints imposed by SMP but had taken account of the preliminary results of the student and staff questionnaires completed during the first year of the experiment. The design of these new videos is considered in more detail in Chapter 6. However it was hoped that these new resources could be included in the experiment. The first of these new videos was "Motion" which fitted well into the Exeter College scheme of work during the second half of the first term. The second "Momentum and Collisions" unfortunately went beyond the scope of the scheme of work and was therefore not included in the revised programme.

The broad aims of the teaching package as described in section 4.3 also applied to the new section, which had specific objectives as listed below.

(i) To introduce students to the particle model of motion and in particular the case when motion is in a straight line, making them aware of the simplifying assumptions that are needed in these cases.

(ii) To provide opportunities for students to draw distance-time graphs for real data provided on the video and to interpret the motion from them. In addition the video was to introduce the concept of average speed.

The new video was welcomed by the staff at Exeter College and readily accepted into their teaching programme. The video was supported with teachers notes, video worksheets and non-video worksheets as for all the other sections of the package. A copy of the new section is also included in appendix B. The revised contents of the teaching package are listed in Table 6.

BLOCK 1 - Motion, Forces and Newton's Laws (Autumn / Spring Terms) 1. "Motion" 2. "Newton's First Law" 3. "What is a Force ?" 4. "Action and Reaction"
BLOCK 2 - Momentum, Projectiles and Circular Motion (Summer / Autumn Terms) 1. "Introduction to Momentum" 2. "Parabolic Path of a Projectile" 3. "The Optimum Angle" 4. "Acceleration at Constant Speed" 5. "Dynamic Analysis"

Table 6 - The Revised Outline of the Teaching Package

CHAPTER 5 - THE DATA COLLECTION METHODS USED IN THE PROJECT

5.1 Introduction

This chapter describes how the various tests and questionnaires used in the experiment were developed and modified during the course of the investigation. The two sections of this chapter deal first with the tests of understanding and the second with the questionnaires used for the video evaluation and the gathering of background information about the students. For the tests of understanding the aims of each test are listed and the way in which these were met. For the questionnaires the purposes for administering each questionnaire is stated and then the way in which the questionnaire fulfils this purpose is described.

5.2 Preparation of the Tests of Understanding

5.2.1 General Guide-lines

At the planning stage it was decided that the video teaching package would be used over two terms as this would match well with Exeter College's proposed teaching scheme, would allow the experiment to be repeated with two different year groups and provide some feedback on the progress of the project at an early stage. As the teaching was to be spread over three terms it seemed appropriate that the students should be tested at the end of each of these terms. In addition as it was impossible to select the students for the experimental and control groups at random, it was essential that a pre-test was also used to confirm the initial equivalence of the groups.. Thus four tests had to be developed for assessing student understanding at each of the four stages described above.

The purpose of the pre-test was to provide evidence that before the video teaching package was used the groups to be involved in the experiment had comparable levels of understanding of mechanics. This was in addition to more general information, gathered using a background questionnaire, that supports the equivalence of the groups. This comparison forms an essential component of the experiment because the groups could not be selected at random. It was hoped that the test would indicate that there were no statistically significant differences between the groups. These details are discussed more fully in the design of the experiment.

The post-tests would concentrate on the material that had been covered in each of the two parts of the teaching package. Here the questions would need to be used to assess student understanding of the concepts covered, so each post-test would contain only questions that were relevant to that terms work. As the post-test would be used to indicate the degree of success that could be attributed to the video it was hoped that this test would show a statistically significant difference between the two groups.

A consideration not relevant to the pre-test, but very important in the design of the post-tests, was that the questions did not ask about specific aspects of the video, but concentrated on the concepts themselves. This was to ensure that it was understanding and not recall that was being measured.

Before any attempts were made to prepare the questions to be used in this evaluation, a detailed study of existing research was undertaken. This study, which has been reviewed in sections 2.1 and 2.3, provided the basis for the approach taken in the design of the questions.

The only existing test found that was remotely suitable was the mechanics diagnostic test prepared by Halloun and Hestenes (1985a). However for several reasons this test was not appropriate for this task. Firstly as a pre-test was required it would be undesirable to use a test that used terminology which the students had not been introduced to. Secondly although it did relate to some of the concepts covered in the teaching package it did not match the topics covered that closely. Although the test could not be used as it stood it was possible to use some of the approaches taken in its questions.

As a first step in preparing the questions, a list of the misconceptions that have been identified was drawn up for those topics that were to be included in the teaching package. These could then be used alongside the concepts that were being taught by the package. Identifying potential student misconceptions at this stage was vital, as these would provide a good measure of the students understanding of the particular concept. Many of the misconceptions that have been identified arise when students attempt to apply concepts to a real situation, rather than a standard textbook problem. These misconceptions are detailed in Table 7. Trowbridge and McDermott (1980) had found that although students could attempt standard textbook problems they often could not apply these concepts to actual motions. In determining student understanding it was therefore decided that the questions should be of a non-numeric nature that did not closely resemble standard text book questions. The questions would be designed to test qualitatively whether students understood the key factors of a particular concept or topic, by asking them questions in which consideration of these factors was important. The questions would also examine the extent to which misconceptions were present among the students both before and after instruction. In devising the questions the table of misconceptions would obviously be useful. In addition Table 8 which lists the key factors associated

with each concept was also prepared to act as a guide in the preparation of the questions.

<p>Kinematics Velocity defined as distance over time. Trowbridge and McDermott (1980). Distance, velocity and acceleration not well differentiated. Trowbridge and McDermott (1981). Implying that equal positions imply equal speeds. Trowbridge and McDermott (1980). Difficulties in drawing graphs of kinematics concepts. McDermott et.al.(1987). Poor quantitative understanding of acceleration. Trowbridge and McDermott (1981). Assuming that constant speed implies constant acceleration. Jagger (1987).</p>
<p>Newton's First and Second Laws In the absence of forces objects remains at rest. Halloun and Hestenes (1985b). Motion is maintained by a force that is exerted in the direction of motion. Halloun and Hestenes (1985b). Force is proportional to velocity. Halloun and Hestenes (1985b). Acceleration is due to an increasing force. Halloun and Hestenes (1985b). Forces accelerate objects to a critical speed. Halloun and Hestenes(1985b). Motion is determined by the largest force. Halloun and Hestenes (1985b). Motion is opposed by an intrinsic resistance. Halloun and Hestenes (1985b).</p>
<p>Newton's Third Law No awareness of need for reaction forces. Minstrel (1982). The greater mass exerts the greater force. Halloun and Hestenes (1985b). The object causing the motion exerts the greater force. Halloun and Hestenes (1985b).</p>
<p>Momentum Confusion with kinetic energy. Backhouse (1964).</p>
<p>Projectile Motion / Gravity Heavier objects fall faster. Halloun and Hestenes (1985b). Components of motion not independent. Whitaker (1983). Unable to draw paths of objects when a force applied to a linear motion. Gunstone (1987). There is no gravity on the moon. Watts and Zylbersztajn (1981).</p>
<p>Circular Motion Circular motion continues in the absence of external forces. McCloskey et.al. (1980). The above motion slowly becomes more linear as time passes. McCloskey et.al.(1980). There is a force in the direction of motion. Gunstone (1987).</p>

Table 7 - Summary of the Misconceptions Identified by Research

<p>"Motion" The use of the straight line particle model, being aware of assumptions made. Using data to plot graphs and interpret them.</p>
<p>"Newton's First Law" That motion is uniform in the absence of any net force. That a force will cause a change in motion.</p>
<p>"What is a Force ?" That forces cause changes to the motion of objects. That if there is more than one force acting then all the forces must be considered. That if the resultant force is zero then motion is uniform.</p>
<p>"F=ma : Newton's Second Law" The relationship between the acceleration, mass and force.</p>
<p>"Action and Reaction" That whenever a force is exerted there is also a reaction force. That the reaction force is equal in magnitude but opposite in direction to the applied force.</p>
<p>"Introduction to Momentum" That momentum is the product of mass and velocity. That momentum is a vector quantity.</p>
<p>"The Parabolic Path of a Projectile" That the path of a projectile is parabolic. To be able to calculate the path of a projectile. The independence of the horizontal and vertical components of motion.</p>
<p>"The Optimum Angle" That there are two angles which give the same range. Projecting at an angle of forty five degrees gives the maximum range.</p>
<p>"Acceleration at Constant Speed" That the acceleration of an object describing a circle is directed towards the centre of the circle. The acceleration depends on the radius and rate of rotation. That if the force causing this acceleration is removed then the path will be a tangent to the circle.</p>
<p>"Dynamic Analysis" That the force causing vertical circular motion varies. For a particular circle there is a minimum rate of rotation.</p>

Table 8 - Key Factors Associated with each Video

From these two tables it was possible to design sets of questions relating to each topic that incorporated the key points of the concept or relationship, while also specifically searching for the presence of misconceptions. The details of the design of the questions for each particular test are set out later in this chapter.

In addition to providing data for the statistical analysis it was hoped that the tests would provide an insight into the ways in which students understand concepts and relationships in mechanics. Gunstone (1987) described how he felt that the use of multiple choice questions had prompted students to give the correct answers. For these two reasons it was decided that a multiple choice format would be unsuitable and that a more open ended style would be appropriate. However the questions would be structured so that very specific issues would be addressed by each question.

Once the test had been drawn up they were tested extensively before they were used with the students involved in the experiment. As a first stage in the process a group of polytechnic students studying an introductory course in mechanics took the tests. These were administered at stages that would correspond approximately to the stage that the experimental groups would have reached at the time they took the tests. A-level students in local schools then also took the test when they had also reached suitable stages in their studies. These groups were selected from schools where the students could be expected to be similar to those taking part in the experiment.

In the light of these trials, revisions were made to the questions on each of these tests. These revisions fell into two categories. Firstly there were the questions that the students could not interpret clearly, and needed clarifying. Secondly there were questions which students could answer correctly without

understanding why their answer was correct or for the wrong reasons. Suitable modifications were made after each trial until the test was satisfactory.

The results of all the trials were recorded and the different responses tabulated to aid the investigation of student understanding of mechanics concepts, some of these results are discussed in Chapter 8.

5.2.2 The Development of the Pre-Test Questions

The pre-test aimed to take the concepts that were covered in the teaching package and assess the students intuitive understanding of them. This would be done by asking questions that require the students to use the concepts to predict the outcomes in various situations. Additionally a small number of questions would examine student understanding of the kinematics concepts that they would have already covered in the early stages of their studies.

At the time that the students would be taking the pre-test, they would have met some kinematics but no other areas of mechanics. For this reason the only technical terms to be used in the test would be velocity and acceleration. Terms such as force or momentum would be deliberately avoided, with informal language used instead. Within the test the questions would not be ordered in any way but mixed up so that students would be encouraged to give equal thought to each concept area and also not be influenced by answers to earlier questions. The questions that formed the pre-test used in the first year of the experiment are contained in Section 1 of Appendix C.

Parts of the test aimed to look at student understanding of the concepts of velocity and acceleration, by examining problems that have been identified by previous research. Questions 7 and 17 fall into this category. The first of these

relates to research by Jagger (1985), which reported on students lack of understanding of the vector nature of acceleration. The second is based on the findings of Trowbridge and McDermott (1980), who explained how many students used a position criterion for comparing speeds. In addition question 4(ii) was used to assess student understanding of the vector nature of velocity.

Gravity, although not covered in detail in any specific video, was included in the pre-test because of its fundamental importance in mechanics and its relevance to several of the videotapes. Roper (1985) has commented on how unexpectedly poor student understanding of gravity appears to be, suggesting that it would be useful to explore this area further. Thus questions 9, 15 and 19(b) were included in the test. The first of these examined the students understanding of the role of mass in determining the effects of gravity on an object as it falls from rest, both on the earth and the moon. Question 19(b) took this further as Roper (1985) had identified that some students do not expect there to be any gravity on the moon. The other question, number 15, assessed student understanding of the effects of gravity on a moving object.

The remaining questions concerned themselves with the students intuitive understanding of the concepts and relationships that were associated with the topics to be covered by the videotapes to be used in the experiment. These questions required the students to understand the concepts that they were familiar with, either through science teaching or from their experiences of the world around them.

Newtons first law is covered by the first video. Halloun and Hestenes (1985b) are just one pair of researchers who have identified how students often feel that a force must be present if motion is to continue. Some questions concern objects moving in a straight line, while others are associated with circular or projectile

motion and require the application of Newton's first law. Questions 1(ii) and 13 require students to recognise that motion does not change in the absence of any external forces, with question 4(iii) being similar but for the case of no net force. In questions 8 and 10 the students need to realise that none of the forces acting have horizontal components and that therefore their velocity has a constant horizontal component.

The second video concerned the effects of a force on motion, in a very general way, which could be summarised in the statement that a force causes a change in motion and hence when motion changes a net force must be acting. The first aspect of this is considered in questions 1(i) and 20, where a constant force is applied and the students expected to predict the effect of this. These questions are used to check that the students are not associating a constant force with a constant speed, a misconception reported by Viennot (1979). Question 23 is similar, but introduces a force that acts at right angles to the direction of motion for a short time. Question 5, which deals with the second aspect of the statement, expects students to recognise that a force opposing the motion will be required to stop it, and that it will be greater than the force needed to support the object when the motion has stopped.

Newton's second law is considered in one dimension in the third video. Here the content is almost exclusively based on the relationship, $F=ma$ in one dimension. The two main areas dealt with here are the effects of varying the mass of an object or the force acting on it. Mass is considered in questions 1(iv), 14 and 16 where different masses are acted on by the same forces. In question 18 the force is varied and the students are required to predict the effect on motion both after a fixed time has elapsed and a certain distance has been covered.

The final video in the third block dealt with Newton's third law. Here the questions examine whether students expect there to be a reaction force, as Minstrell (1982) had found that a number of students do not expect there to be a reaction force present. Additionally Halloun and Hestenes (1985b) have described how students often feel that the action force or the force exerted by the larger body will be greater. Questions 3, 12 and 19(a) explore these concepts and allow students to demonstrate the presence of these misconceptions if they exist.

The first videotape in the second block presents an introduction to momentum, specifically that it is the product of mass and velocity. Question 2 examines whether it is mass, speed, momentum or some other combination of mass and speed that students consider to be important in determining how difficult it would be to stop a moving object.

The second and third videotapes in the second block are concerned with projectile motion. The first deals with the parabolic path and the second with the angle of projection to maximise the range. Whitaker (1983) has stated that students are often not aware of the independence of the horizontal and vertical components of velocity, particularly that the horizontal component remains constant. Questions 8 and 10 examine this by asking the students about projectiles that have horizontal initial velocities. The shape of the path being parabolic is investigated in question 6, which also goes on to see how students expect altering the angle of projection to effect the range. This is taken further in question 21, which aims to determine whether students understand that for a given speed of projection there are two angles that will give the same range.

The two final videotapes deal with circular motion, in both horizontal and vertical planes. McCloskey et al. (1980) have described how some students do not expect a body that was describing a circle to follow a tangential path when

the constraining force is removed. This misconception is covered by questions 4(i) and 11. Question 7, as well as looking at acceleration in general, allows the students to demonstrate an understanding of the acceleration required for circular motion. Student understanding of the effect of the radius on the required acceleration and hence the force is explored in question 22, which also focuses on the understanding of motion in a vertical circle. Here students are given the opportunity to include gravity when making predictions about the force acting.

Thus these questions only look briefly at the mechanics that the students have already covered, but concentrate on discovering students intuitive ideas about the concepts that will be included in the video teaching package. Table 9 indicates which questions are associated with which concept.

Concept	Question Numbers
Kinematics	4(ii), 7, 17.
Gravity	9, 15, 19(ii).
Newton's first law	1(ii), 1(iii), 4(iii), 8, 10, 13.
Newton's second law	1(i), 1(iii), 1(iv), 5, 14, 16, 18, 20, 23.
Newton's third law	3, 12, 19(i).
Momentum	2.
Path of a projectile	6(i), 8, 10.
Range of a projectile	6(ii), 21.
Circular motion	4(i), 7, 11, 22.

Table 9 - The Questions Associated with each Concept

5.2.3 Modifications to the Pre-Test Questions for Year Two of the Experiment

In order to match the pre-test with the modified teaching package and programme of implementation the following modifications were made to the pre-test questions.

(i) Removing the questions on velocity and acceleration that the students would have covered before the administration of the pre-test in the first year, but not in the second. These questions were numbers 7 and 15 of the original test. Question 4 was revised so that it used the word speed rather than velocity.

(ii) Removing the questions based specifically on the relationship $F=ma$ that had been covered in a video that was not to be used in the second year. These were questions 14, 16 and 18 of the original test.

(iii) Inserting questions on the drawing and interpretation of distance-time graphs. There were in fact three new questions, the criterion for the selection of which are now described here.

The numbering of the original test questions was altered to allow for the reduced number of questions and the insertion of the new ones, but all the other original questions were retained in the same form as on the first version of the test. The questions used on the revised pre-test can be found in Section 2 of Appendix C.

The difficulties that students have drawing and interpreting graphs of kinematic quantities has been reported by McDermott et al. (1986). This paper had identified several types of difficulties that students encountered when either drawing conclusions from a graph about a physical situation or drawing a graph given information about a physical situation. There were three specific difficulties that were relevant to the content of the "Motion" video and each of these was used as a basis for the additional pre-test questions.

The first of these difficulties arises when students attempt to reach conclusions about the speed of a body from a distance-time graph. Some students will expect the height of the graph rather than the slope to give the speed of the body. The

first of the additional questions, numbered 14 on the revised pre-test, was designed to identify students who used this incorrect strategy, when comparing two straight line graphs.

The second area of difficulty relates to interpreting the significance of the gradient of a distance time graph. Common difficulties are those such as assuming that a horizontal line represents motion at constant speed and that any curve moving upwards represents an increasing speed, regardless of its gradient. The second of the additional questions, numbered 17, considers these difficulties by presenting a graph with three distinct parts which represent increasing speed, constant speed and zero speed. The students are asked to describe how speed is changing on each part of the graph.

The third area of difficulty concerns the students' ability to draw a graph when presented with a physical situation. One of their main observations was that students expect the shapes of graphs to resemble the motion that takes place. For example a student may draw a U shaped distance-time graph for a body that moves along a U shaped track. The third of the new questions, numbered 21, tested student ability in this skill by asking them to draw a distance-time graph for a car moving on a U shaped track.

No questions on modelling and the idea of particles were used on the pre-test as it was assumed that very few of the students would be familiar with the associated terminology.

5.2.4 The Development of the Motion Post-Test Questions

The motion video introduced the idea of modelling motion and the use of distance-time graphs. Student understanding of both these ideas were tested with

the questions that can be found in Section 3 of Appendix C. There are two questions on the modelling aspects and two on the use of graphs to describe motion. Question 1 asked the students to state the assumptions that would have to be made if two simple situations were to be modelled with particles, in order to test whether the students had grasped the significance of the particle model. In particular it wanted to test if students understood that the use of a particle model required simplifying assumptions that would hide many of the features of the motion being modelled. Question 3 also had the same aim but asked the students to criticise a model that was given.

Two questions were also included to test the students abilities in drawing and interpreting graphs. Question 2 which required the students to draw a distance-time graph for a situation that was described in the question. This was in fact the same as question 21 of the pre-test used in the second year of the experiment. It was repeated because of the poor performance of students on this question at the pre-test stage. Question 4 was designed to test if students understood the meaning of average speed and that the gradient of a graph gives the speed rather than the height.

5.2.5 The Development of the Force Post-Test Questions

These questions were aimed to assess student understanding of the forces topics covered in block one of the teaching package, and can be found in section 4 of Appendix C.

The first of the videos in this block covered Newton's first law. The main concern here was that students should have got over their intuitive ideas that a force was required to maintain motion and have gained an understanding that an objects natural state can be in motion. Questions 5(ii) and 19(ii) present

situations in which a force that was acting on an object has been removed, and ask the students to predict what happens to their speeds. The path of an object in this situation is also considered in questions 19(i) and 21(ii), which require students to draw the paths of objects that were describing curved paths before the forces were removed. A final question, number 9, in this section was included to examine if students could describe the conditions under which a body could be made to move with constant velocity.

The second video was concerned with forces, their effects on motion, their identification and determining if a given situation is in equilibrium. These ideas were reflected in several groups of questions. The first of these involved determining if the forces in a given situation were in equilibrium. Question 1 which presented four such situations, also asked for the direction of the resultant force if there was one. The identification of forces acting was considered in questions 10, 12(i), 14 and 19(iii), where the students were asked to mark the forces acting on a diagram using arrows. This idea was extended in question 4 where the students were asked to mark in the direction of the resultant force in various situations. These questions make it very obvious when students have misconceptions that make them expect there to be a force in the direction of motion. The point of application of the force, an important aspect of an understanding of force, was also considered briefly in question 2(ii).

Newton's second law was the subject of the third video. The questions here focused on the one dimensional applications of the law, as in the video, but also sought to establish if students could extend these ideas to two dimensions. The first point to be tested was that a force would cause a body to accelerate as long as it was applied. On the pre-test a maximum speed misconception had emerged, which is described in section 8.3. Questions 5(i), 6 and 7(ii) dealt with this idea, the first applying the force for a short time and the others continuously. The

understanding of the relationship $F=ma$ was also explored, with questions 8(ii) and 11 examining the effects on the motion of changing the mass, while the consequences of altering the applied force were considered in questions 2(i), 5(iii), 5(iv) and 17. The law is extended to two dimensions in questions 16 and 21(i), where the students are asked to draw the path of an object, when the force acts perpendicular to its original path, either for a short time or continuously. In addition question 7(i) asked students to find the force that would need to be added to an existing force if it were to make an initially stationary object move in a specified direction.

The final video used on the third block presented an introduction to Newton's third law. There were two main misconceptions that held back student understanding of this law. Firstly, as reported by Minstrel (1982), was students failure to recognise the existence of reaction forces, which was examined in questions 8(i), 10 and 13. The second problem was concerned with the magnitude of the reaction force. Halloun and Hestenes (1985b) have described how often, students expect the action force to be larger, or the force acting on the greater mass to be larger. Student understanding of the magnitude of reaction forces was examined in questions 10, 13, 18 and 20, which were designed to indicate the presence of either of these misconceptions. Question 15(i) was included to test for students who expect there to be reaction forces that do not exist.

Gravity was a concept that was mentioned on several of the videos, although not explored in great depth. It therefore seemed appropriate to include some questions on this concept to see if student understanding had improved during the course of the experiment and so all came from the repeated questions. Questions 3, 12 and 15(ii) examined this concept. Question 12 had originally

asked about acceleration, when used on the pre-test, but was reworded to ask about force which was more appropriate here.

It had been decided that some of the pre-test questions should be included in the post-tests. These questions would be those that related to the topics under consideration and those with which students had difficulty on the pre-test. These questions are listed in Table 10 which indicates the numbers assigned to that question on both tests.

Post-Test	3	6	12	13	15	16
Pre-Test	9	20	15	12	19	23

Table 10 - The Numbers Assigned to the Pre-test Questions Repeated on the Force Post-test

Thus this test contained a variety of questions, some new and others repeated from the pre-test, which covered the important ideas associated with the concept of force. It did not just test for the ideas presented on the videos, but looked at student understanding of force as a whole. This approach would measure real understanding rather than test for the recall of specific ideas seen on the video.

Table 11 summarises the allocation of questions to different topics.

Concepts / Topics	Questions
Newton's First Law	5(ii), 9, 19(i)(ii), 21(ii).
Forces in equilibrium	1.
Identification of forces	4, 10, 14, 19(iii).
Point of application	2(ii)
Newton's second law	2, 5(i), 5(ii), 5(iii), 5(iv), 6, 7, 8(ii), 11, 16, 17, 21(i).
Newton's third law	8(i), 13, 15(i), 18, 20.
Gravity	3, 12, 15(ii).

Table 11 - The Topic Areas to Which the Force Questions Relate

5.2.6 Modifications to the Force Questions for Year Two of the Experiment

Due to the modifications to the video content of the teaching package there were a number of modifications to the questions on the concept of force. The questions that were modified can be found in section 5 of Appendix C.

As the video on Newton's second law had been removed the questions which had been designed to test student understanding of this law were removed. Only question 11 was actually deleted, while others had parts removed or alterations made. The parts of question 5 labelled (iii) and (iv), which referred to the effects of a force on different masses, were deleted but the initial part of the question was retained as it stood. Question 8(ii) that asked about the acceleration of two particles subjected to the same force was also deleted, but the first part of the question was left unchanged. Question 17 retained its three parts but each asked only about the velocity of the spacecraft and not its acceleration.

5.2.7 The Development of the Momentum Post-Test Questions

The momentum video provided a simple introduction to the concept of momentum, emphasising the importance of mass and velocity to this concept. The post-test questions that were used to test student understanding of this concept can be found in Section 6 of Appendix C.

The key points to be examined by these questions were the roles of both mass and velocity in forming the quantity and the fact that it is a vector quantity. Student understanding of this combination of mass and velocity is tested in questions 2, 4, 5, 6 and 8, which present different situations where the concept

needs to be applied. It had emerged from interviews with students that the vector nature of momentum is often disregarded or not considered at all, so questions 4 and 7 concentrated on this aspect of momentum. Confusion between momentum and both the concepts of force and kinetic energy had been observed in students so questions 1 and 3 were included to test for the presence of these problems.

As with all the other post-tests some questions from the pre-test were repeated. In this case it was only pre-test question 2, which became question 6.

5.2.8 The Development of the Projectiles Post-Test Questions

The two videos on projectiles were "The Parabolic Path Of a Projectile" and "The Optimum Angle". The questions designed to test student understanding of the concepts covered in these two video are described here, and can be found in section 7 of appendix C.

The first video was concerned with the path of a projectile, concentrating on the derivation of an equation for its path and demonstrating that the horizontal and vertical components were independent. Whitaker (1983) has reported on students' poor understanding of this independence, which is tested in questions 1, 5, 7 and 8. They give situations where the students need to recognise that the horizontal components of velocity remain unchanged or that the vertical ones are identical. The understanding of the parabolic nature of the path is examined in question 3(i). In addition question 6(i) asked students to identify the forces acting at various positions of the projectile, allowing the detection of those students who expected there to be a force acting in the direction of motion.

The final video derived an expression for the range of a projectile. This was then used to demonstrate that the maximum range would be achieved for an angle of projection of forty five degrees and that there were two angles for all other attainable ranges. These two ideas were examined in questions 3(ii), 4, 6(ii) and 9. In addition question 2 examines whether students recognise that the range of projectile is not dependent on its mass.

As with all the post-test topics some questions from the pre-test were repeated from the post-test. In this case the numbers of the repeated questions are given in Table 12.

Projectiles Question Number	1	3	4	8
Original Pre-Test Question Number	8	6	21	10

Table 12 - The Numbers Assigned to the Projectiles Questions Repeated From the Pre-Test

5.2.9 The Development of the Circular Motion Post-Test Questions

These questions were designed to test student understanding of circular motion in the cases where it took place in either horizontal or vertical planes at constant speed. They can be found in section 8 of appendix C.

The first of these two videos concentrated on demonstrating that the acceleration of an object describing circular motion was directed towards the centre of the circle and hence that the resultant force must act in the same direction. It also illustrated that the magnitude of this acceleration depended on both the radius and rate of rotation. Both Helm (1980) and Warren (1979) have noted the problems that students have identifying the forces acting on bodies describing

circular motion. Questions 1 (adapted from Warren) and 2(iv) ask students to identify the forces in two situations, while question 4 asks about acceleration. McCloskey et al. (1980) have reported how students expect that the circular motion of a body would continue, even after the constraining forces had been removed. So questions 5 and 6 were included to test for the presence of this misconception. In addition questions 2(i)-(iii) and 8 tested the students' understanding of the relationship between acceleration, radius and rate of rotation.

The second video concentrated on vertical motion, and in part on circular motion. It was this aspect of the video that was of the most interest. Questions 3 and 7 were aimed at this video, both examining student understanding of the forces acting, while the second of them also asked about the difference between the forces acting when the object failed to continue its circular path.

As with all the other post-test questions some of the pre-test questions were repeated. The numbers of these questions are listed in Table 13, which also indicates the question numbers assigned in the original pre-test.

Circular Motion Question Number	4	6
Original Pre-Test Question Number	7	11

Table 13 - The Question Numbers Assigned to the Repeated Circular Motion Questions

Thus these test questions examine student understanding of circular motion and would allow an evaluation of the effectiveness of these two video tapes to be undertaken. Table 14 provides details of how the questions relate to either horizontal or vertical circular motion.

Topic / Concept	Questions
Horizontal circular motion Vertical circular motion	1, 2, 4, 5, 6. 3, 7.

Table 14 - The Topic Areas to Which the Test Questions Relate

5.3 Design of the Questionnaires

5.3.1 The Background Questionnaire

As described in Chapter 4 the purpose of this questionnaire was to provide information about the backgrounds of the students. This information would help to decide whether the groups that were available in the college could be regarded as equivalent for the experiment. Of the areas of concern that had been identified in section 4, those that related specifically to individual students were;

- (i) academic ability,
- (ii) physics teaching,
- (iii) sex.

In addition, as the college had a number of mature students, age was also considered to be a relevant factor.

The questionnaire firstly asked students to identify themselves and to state their teaching group. They were then asked the straightforward questions about their age and sex.

In order to assess whether they were likely to be receiving any teaching that would influence their learning of mechanics they were asked to list all the

courses that they were currently following. This would reveal if they were studying physics or any other subject that may influence their learning of mechanics.

To assess the students' academic ability they were asked to list all their GCSE/GCE/CSE subjects taken along with the dates when the examinations were taken and the grades that they obtained on them. It was felt that this information would be the best indicator of the students past academic achievement.

A copy of this questionnaire can be found in section 11 of Appendix C.

5.3.2 The Student Video Evaluation Questionnaire

The purpose of the student video evaluation questionnaire was to gauge the reactions of the students participating in the experiment to the videos used. Hays (1973) has stated how teacher's committees evaluating educational television in Hong Kong, are considering the use of student questionnaires on a very large scale, to make a valuable contribution to their programme planning. It was anticipated that the use of this type of questionnaire would yield information, that would allow comparisons to be made of the video resources from a student viewpoint. In particular this could be used to identify the aspects or approaches that students liked or disliked. This type of information could ultimately be of use to the producers of future video resources in the way that Bates (1981) has described.

The questionnaire adopted a mixed approach with an initial section of questions with fixed responses and a second section with more open-ended questions. The fixed questions were very much designed to assess the students' reception of the

video while the second section contained questions that would probe more into the reasons for this reception.

The key aspects of the students reaction to the videos were regarded as;

(i) their perception of the quality of the reproduction of the video,

(ii) their interest in the video,

(iii) their rating of the videos ability to communicate with them.

The first and third of these aspects were split into two components. For the first into sound and picture quality. For the second into quality of the explanation on the video and the students understanding of what they had seen. These five factors then each formed the basis of one question. A four point scale was selected for the format of the possible responses, with two negative and two positive categories. Some initial experiments with a five point scale containing a central neutral point produced little useful feedback, as many students simply opted for a central average option. This format would provide quantitative information that would give an assessment for one video that could be compared with another.

Thus the first part of the questionnaire provided an quantitative assessment of the effectiveness and quality of the video from a students viewpoint. This in itself does not provide the sort of information that a producer requires and so the second part of the questionnaire aimed to look for the reasons for these reactions. The questions focussed on the following points;

(i) What the students felt that they had gained from watching the video.

(ii) What had assisted or detracted from making the watching the video a valuable experience for the student.

The first of these points was covered by asking the students what they felt they had learned from the video. The second was covered by three questions. The first asked what the students had liked most about the video while the second asked about what they had disliked most about the video. The third question provided further scope for comments by asking the students what they would like to change about the video. All four of these questions were completely open-ended to allow the students the freedom to make a wide range of responses. It was however anticipated that patterns would emerge from these responses that could be used to explain the students assessment of the videos given on the first part of the questionnaire.

Thus it was anticipated that the first part of the questionnaire could be used to assess the video and the second part to explain this assessment and hence provide guide-lines for producers of new resources. A copy of this questionnaire can be found in section 12 of Appendix C.

5.3.3 The Staff Video Evaluation Questionnaire

The regular teacher in the classroom is probably the person most able to evaluate how video resources are received when used in the situation which they were designed for. External monitors or teachers using video on one off occasions may not be able to judge the students true reaction to the video. Therefore the regular teacher of a class is in a unique position to evaluate the suitability of a video for the group, and be able to provide an insight into the groups reaction to the video.

Haye (1973) has described the importance that has been placed on teachers evaluation of educational television in Hong Kong. He described the role of teachers in the initial design of programmes and the importance of teacher evaluation of the programmes in use. It would seem to be important to gather as much feedback from teachers as possible but not to burden them with a major task after each video. For this reason a fixed response questionnaire was produced, which also gave teachers an opportunity to add any further comments that they had about the video. Each of the questions would have three possible responses.

The staff evaluation questionnaire had three main aspects. Firstly the technical quality of the video, particularly the sound and picture quality. These aspects were covered in the first two questions that asked specifically about these aspects of the video.

The second aspect was the suitability of the content and the presentation of the video for the students that were viewing it. This was broken down into six questions about specific factors relating to the video. These factors are listed below.

- (i) Student interest in the video.
- (ii) The achievement of the aims of the video.
- (iii) The number of teaching points.
- (iv) The level of the video.

(v) The pace of the video.

(vi) The presentation of the video.

On the questionnaire the teachers were asked to rate each of these factors on a three point scale.

One final question that allowed the teachers to express their overall opinion of the video was also included, which asked the teachers whether or not they would use the video again. At the end of the questionnaire teachers were asked to add any comments that they had about the video. The intention of this was to allow teachers to expand on their responses for any of the other questions or to raise issues that had not been covered by them. A copy of this questionnaire can be found in section 13 of appendix C.

It was anticipated that the teachers responses to these questions would provide further information about the suitability of existing videos as well as assisting the development of guide-lines for producers.

CHAPTER 6 - THE FORMULATION AND APPLICATION OF A MODEL FOR MECHANICS VIDEO PRODUCTION

6.1 Introduction

This chapter begins by looking at the evaluation of the videos used in the experiment at Exeter College. The responses of the students and their staff to the videos are considered and the strengths and weaknesses of each video are identified. These responses provided a new source of data, which then facilitated the formulation of a model for the production of new video resources for the teaching of mechanics. This was the first time that such a model for mechanics in particular or mathematics in general has been formulated from research findings. This model was developed from the students reactions to the videos and then applied to the production of two new video resources for the SMP's new A-level course Mathematics 16-19. At the time that the research was being conducted, there were 32 schools and colleges piloting this new course and several of these were prepared to provide feedback on the two new videos as they were used by their students. These schools and colleges returned more completed evaluation questionnaires which were analysed and again stressed the importance of some aspects of the model. Finally the chapter closes by looking at how the two videos were refined and subjected to further evaluation on a smaller scale.

6.2 Evaluation of the Videos Used in the Exeter College Experiment

6.2.1 Procedure

This section contains reports on the evaluation of the videos used in the experiment at Exeter College. As each video was watched by the students they were asked to complete the questionnaire described in section 5.3, as were the their class teachers. Some of the videos were also used with other groups of students, either in their own schools or visiting the Polytechnic, who along with their normal teachers also completed questionnaires. The results from both these sources are reported and discussed here.

The report on each video presents the results of part 1 of the questionnaire and also a summary of the responses to part 2. As only a very small number of teachers completed questionnaires their responses are not presented in their entirety, but interesting comments and responses are noted.

The format of each report is that each of the following areas are considered in turn;

(i) sound and picture quality;

(ii) student interest in the video;

(iii) student impressions of the quality of explanation and their own understanding of the video.

The summaries of the responses to part 2 and the remarks by the teachers are used to find reasons to explain the students responses to each of the questions in part one, for each of the three categories listed above.

Each of the videos used in the Exeter College experiment is reported on in turn, with the exception of "Dynamic Analysis". This video has been omitted because it was seen only by a total of 12 students, due to the loss of students in year 1 and its removal from the teaching programme in year 2.

6.2.2 Evaluation of the Video "Newton's First Law"

This video was seen by a total of 76 students, most of whom were from the Exeter College groups. Their responses for part 1 of the questionnaire are recorded in Figures 1, 2 and 3, while their comments on part 2 are summarised in Table 15.

The rating of the technical quality of this video by the students was reasonable, with 61% and 75% of the students rating the sound and picture quality respectively as excellent or good. A similar view was expressed by the teachers. There were two main points raised by the students with regard to these factors in part 2 of the questionnaire. The first of these was the disturbing background noise at the ice rink, noted by 8% of the students on question 7. This background noise was presumably included in the video to add atmosphere to the ice rink scenes, but in fact distracted some students. It was also probably responsible for the sound quality being rated lower than the picture quality. The second was the poor quality of the text, used at the beginning of the video to state Newton's laws, that was noted by 14% of the students on question 7. It was interesting to note that while most of the comments about the text focussed on its illegibility, some also stated that there was not enough time to read it.

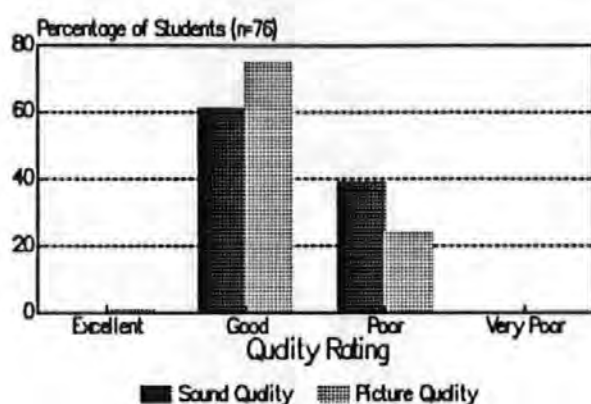


Figure 1 - Student Evaluation of the Sound and Picture Quality

The students' interest in this video was high with 67% of the students stating that it was either interesting or very interesting. The teachers also felt that student interest was at a fairly high level. The students' responses to question 6 on part 2 of the questionnaire, show that a good number of students liked the way that examples were used in this video or made reference to seeing familiar situations. In the video much of the programme was centred about discussion of real objects, particularly a horse and cart and the motion of a puck on an ice rink. It seems that this type of approach attracted the students interest. Another point that probably detracted from their interest, by distracting their attention, was the programme presenter. Several comments were made about his appearance, which students found amusing and a change of presenter was suggested by 25% of them. The fact that the presenter in a video only 7 years old gives rise to so much criticism raises questions about the value of using a presenter in this type of programme.

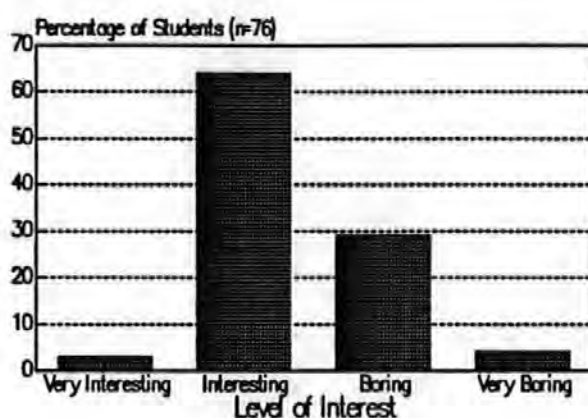


Figure 2 - Student Evaluation of Their Interest in the Video

The students felt that they understood the content of the video well with 86% stating that they understood it well or very well and 79% stating that they felt the explanation on the video was good or excellent. A good proportion (43%) of the students stated that they had learned something definite from the video, with most of these referring to the history of the development of the laws of motion or Newton's first law. Only 5% did not like the explanation on the video, while 11% liked the explanations and found the video easy to understand. The teachers almost all felt that the pace and level of the video was about right and that it achieved its teaching aims.

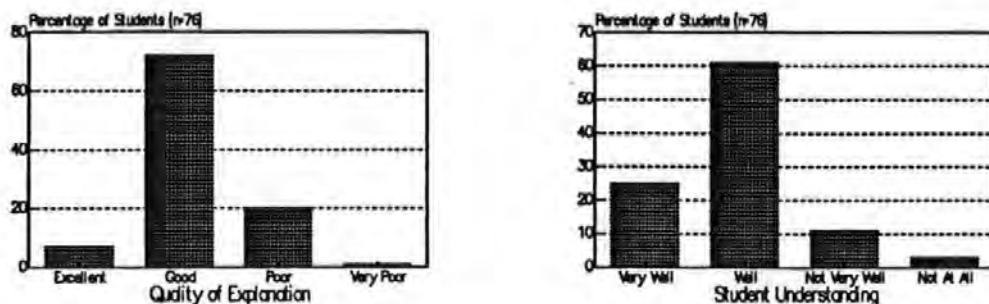


Figure 3 - Student Evaluation of the Explanation on the Video and their Level of Understanding

Question 6	Use of examples Explanations good / easy to understand Brief history Not too long Reference to familiar situations / applications Nothing / nothing in particular	31% 11% 9% 8% 5% 4%
Question 7	Presenter Text difficult to read Distracting background noise Poor explanations Introductory (snooker) sequence Uninteresting situations / examples	26% 14% 8% 5% 4% 4%
Question 8	Presenter Make text easier to read Nothing More examples Improve / expand explanations Change music Update video / examples	25% 21% 20% 5% 5% 5% 4%
Question 9	History of laws of motion About Newton's laws Nothing / not much Nothing new Particles can move in the absence of forces A little about mechanics / motion	22% 17% 11% 11% 5% 4%

Table 15 - Summary of Students Responses to Part 2 of the Questionnaire

This video is clearly one that would have a place in a contemporary mechanics class. Its approach, using discussion about Newton's laws from a historical viewpoint and in relation to real situations, appealed to many students and produced positive learning outcomes for the majority of students. None of the teachers said that they would not use the video again, although some were unsure, while 60% said that they would. There were however three problem areas associated with this video. The first and of most consequence was the use of the presenter, secondly the text on the screen and third the background noise.

6.2.3 Evaluation of the Video "What is a Force ?"

This video was seen by 81 students, most of whom were from the Exeter College groups. The results for part 1 of the questionnaire are recorded in Figures 4, 5 and 6, while the comments from part 2 are summarised in Table 16.

The students regarded the sound and picture quality for this video as fairly poor. 64% and 59% of the students stated that the sound and picture quality were either poor or very poor respectively. These poor results can almost certainly be attributed to the age of the video (17 years) and the fact that it is a copy of an original 16mm film. This response was not supported by the teachers who rated these qualities as good to fair. Suggesting that they were much less critical than the students.

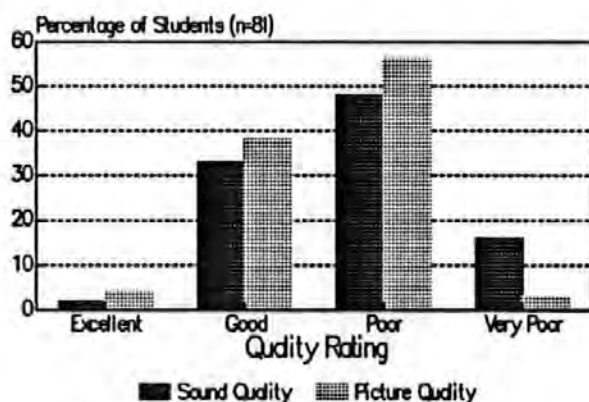


Figure 4 - Student Evaluation of the Sound and Picture Quality

Student interest in the video was fairly low with 68% of the students stating that it was either boring or very boring. The teachers did feel that student interest was better with most describing it as fair. There emerged from the students responses to part 2 of the questionnaire, four possible reasons that could have contributed to the students lack of interest. One is the age of the video. In answering

question 8, 22% of the students stated that they would update the video. Secondly, 32% stated that they felt the video was aimed at a lower age range and was too slow in pace or too basic for them. Several of the teachers also felt that the pace was too slow and the level too low. Arising from this is the third factor, that 30% of the students felt that they had learned nothing or very little from the video. The final point was that the narrator was disliked by 33% of the students, many of whom referred specifically to his accent or his attitude to the viewer.

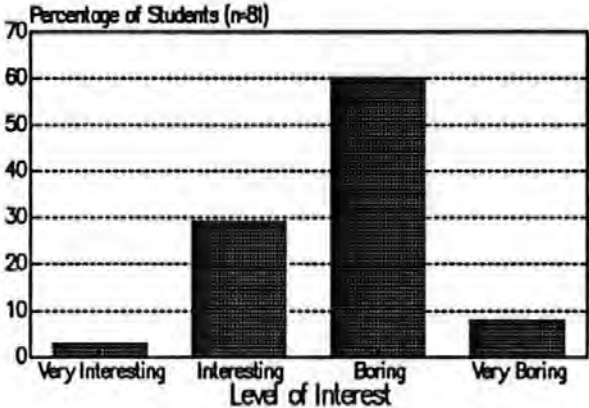


Figure 5 - Student Evaluation of their Interest in the Video

However their ratings of the quality of the explanation and their understanding of the video were more encouraging. With regard to the quality of the explanation 79% felt that it was either good or excellent and 96% stated they had understood it well or very well. These reactions are positive and supported by the comments that some of the students made on part 2 of the questionnaire. In answering question 6, 35% of the students said that they liked the simple easy to understand explanations, while another 20% stated that they liked the examples used. This approach based on a discussion of real examples was again effective, but pitched at too low a level in this case.

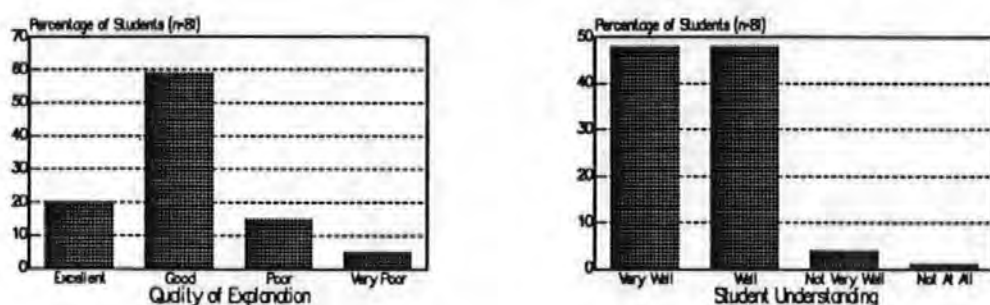


Figure 6 - Student Evaluation of the Explanation on the Video and their Level of Understanding

Question 6	Easy to understand explanation The examples It was too short Nothing The way it defined forces Use of pictures Music	35% 20% 9% 7% 4% 4% 4%
Question 7	Narrator / narrator's accent Too simple / too slow for sixth formers Repetition by narrator Music Poor picture Old style Explanations / demonstrations	33% 32% 7% 6% 6% 6% 4%
Question 8	Update the video Change attitude to viewer Change narrator Improve quality Change music Everything Improve explanations Change examples	22% 15% 14% 14% 11% 6% 5% 4%
Question 9	Nothing / not much What a force is About forces Objects move at a steady speed if in equilibrium Nothing / not much new That a force causes a change in motion About motion	30% 20% 17% 14% 11% 9% 6%

Table 16 - Summary of Students' Responses to Part Two of the Questionnaire

In conclusion it seems that the potential for using this video in a contemporary classroom is small, even though 75% of the teachers said that they would use it again. Its strengths lie in the approach using discussion about real examples to develop the concepts in a simple uncluttered way. Its deficiencies lie in its age, the narrator's voice and the low age level at which it was aimed. It does however provide a framework that could well be adapted to produce a modern updated equivalent of the original.

6.2.4 Evaluation of the Video "F=ma: Newton's Second Law"

This video was seen only by the Exeter College students involved in the experiment, who totalled 41. Their responses to part 1 of the questionnaire are recorded in Figures 7, 8 and 9, with those to part 2 summarised in Table 17.

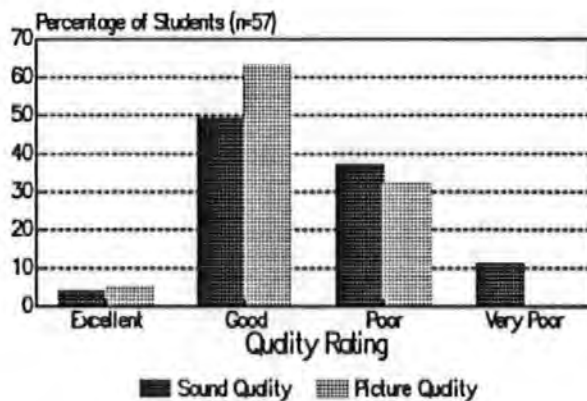


Figure 7 - Student Evaluation of the Sound and Picture Quality

There was a difference between the ratings given to the sound and picture quality of this video. The picture quality was rated as excellent or good by 67% of the students while 52% of the students rated the sound quality as poor or very poor. No real reasons emerged from part 2 to explain the poor opinion of the

sound quality. However when the air-track was used in the studio it produced quite a lot of background noise, that could have explained this reaction. The teachers impression of the picture quality was good, but they also rated the sound quality as good, unlike the majority of the students.

The level of student interest in this video was remarkably low, with 87% of the students stating that it was either boring or very boring. The teachers also felt that the students had not found the video interesting, rating student interest as fair to low. There were no clear reasons emerging from the part 2 questions to explain why the video was so unpopular. There were also several vague comments about the age or uninteresting approach but no one thing stood out. There were a large number of comments about the presenters of a critical nature, with 32% suggesting that the presenters should be changed. In addition the students felt that they learned very little from the video, with 39% of the students stating that they had learned nothing or very little. The teachers suggested that the level was too low and the pace too slow. It seems that the approach of a studio based series of experiments without much reference to reality fails to interest the students, especially if the results are slow to appear and then seem very familiar.

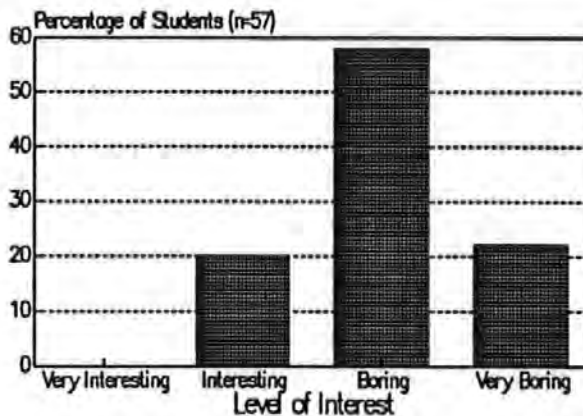


Figure 8 - Student Evaluation of their Interest in the Video

A high proportion of the students felt that their understanding of the video was either good or very good, with 83% of the students giving these responses. Their rating of the quality of the explanation, while reasonable, was not as good with 33% rating it as poor. There was some criticism of the explanations by the students and some also disliked the manipulations and calculations that were used.

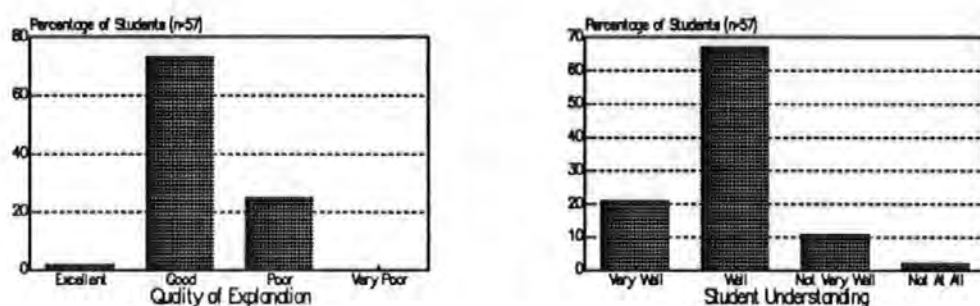


Figure 9 - Student Evaluation of the Explanation on the Video and their Level of Understanding

This video seems to fail desperately to capture the interest of the students. Its approach of experiments not linked to reality and with no justification does not appeal to the students with results that seem too obvious and of little significance to them. The fact that for several of the experiments results appeared with no justification on the screen probably contributed to lack of relevance. This particular video has little or no value in the classroom, probably doing mechanics more harm than good by switching off the students. Any attempt to produce a more interesting video to examine this relationship would need to be based much more on reality and much less on practical work which produces numerical data to be analysed.

Question 6	Air track experiment Visual aids / graphics Simple clear explanations Nothing / not a lot Examples used Making predictions	14% 12% 11% 11% 7% 4%
Question 7	Presenters / presenters appearance Uninteresting / dull approach Explanations Age / out of date Nothing Distracting noises Examples Too much manipulation / calculation	35% 11% 7% 7% 5% 5% 4% 4%
Question 8	Presenters / presenters' appearance Update the video Make it more interesting Virtually all of it Experiments (improve / remove) Nothing Improve sound quality Improve explanations	32% 11% 9% 7% 7% 5% 4% 4%
Question 9	Nothing / not a lot Newton's Second Law About force / mass / acceleration How to apply Newton's Second Law	39% 28% 7% 4%

Table 17 - Summary of Students' Responses to Part 2 of the Questionnaire

6.2.5 Evaluation of the Video "Action and Reaction"

This video was seen by a total of 121 students, from Exeter College and other schools. The responses to part 1 of the questionnaire are illustrated in Figures 10, 11 and 12, while the results of part 2 are summarised in Table 18.

The students' rating of both the sound and picture quality were low, with 78% and 97% of the students respectively stating that they considered these to be poor or very poor. The teachers' rating was similar. The age of the video and the fact that it had been copied from a 16mm original clearly accounted for these responses.

The students' interest in this video was however encouraging with 56% of the students finding it either interesting or very interesting. The teachers' comments also reported that student interest was fair to high. From the responses to question 6, it is easy to see that the experiments producing the colour patterns were appreciated by the students. Also the responses to question 9 where 44% of the students stated that they had learned something relevant from the video, indicated that the students felt that they had gained from watching the video. Some students commented either that they had learned nothing or little from the video, while others suggested that the level was too low. These factors and the poor picture quality probably accounted for most of the students who had not found the video interesting.

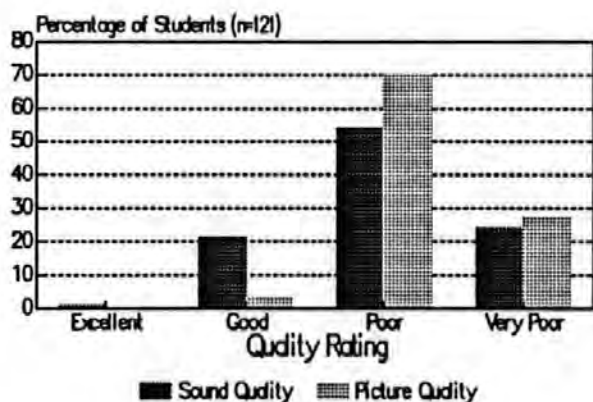


Figure 10 - Student Evaluation of the Sound and Picture Quality

Student understanding of the video and student rating of the explanation were both good. The quality of the explanation was rated as good or excellent by 77% of the students and 82% felt that they had understood the video well or very well. The high level of understanding is reflected in the comments given in response to question 9, already discussed.

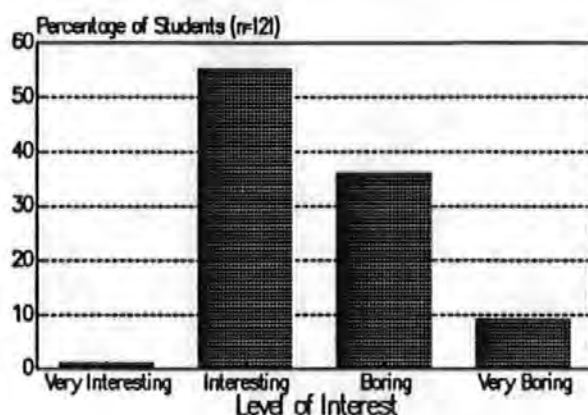


Figure 11 - Student Evaluation of their Interest in the Video

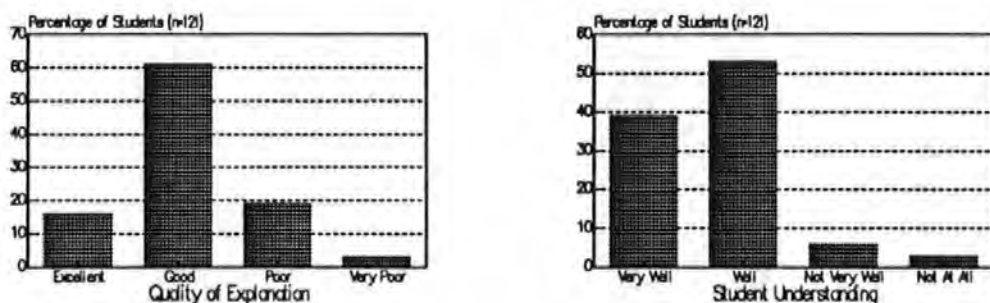


Figure 12 - Student Evaluation of the Explanation on the Video and their Level of Understanding

This video still has a considerable potential for use with students. It would obviously benefit from being updated with a new voice, which would remove almost all the students complaints about poor quality picture and narrator's voice. It is interesting to note that again there is criticism of the narrators voice. All of the teachers who had seen it said that they would consider or definitely use it again. The great asset of this video seems to be the use of the colour patterns which provide a visual image of the ideas under consideration, concentrating on the actual concept and not getting involved in tedious algebra

or calculations. It also links the theory developed to examples, although only in a small way, that could be expanded in a revised version.

Question 6	Experiments showing force by colour patterns Explanations Practical examples Springs at the end	30% 14% 12% 6%
Question 7	Music Poor picture quality It was too basic / slow Presenter's voice / accent Too repetitive / monotonous	42% 26% 13% 12% 10%
Question 8	Change music Improve picture quality The voice Nothing Update it Improve / expand explanations Improve sound quality Better / more interesting examples Everything / most of it Improve clarity of pictures / diagrams Less repetitive / monotonous commentary Speed up pace	26% 19% 11% 9% 8% 7% 7% 6% 6% 5% 5% 4%
Question 9	About action and reaction / Newton's third law Nothing / not much Improved / clearer / reinforced understanding About reaction forces Nothing new Reactions are equal and opposite in direction	16% 16% 13% 9% 7% 6%

Table 18 - Summary of the Students' Responses to Part 2 of the Questionnaire

6.2.6 Evaluation of the Video "Introduction to Momentum"

This video was seen by a total of 50 students, most of whom were participating in the experiment, but also a few from other sources. The responses to part 1 of the questionnaire are illustrated in Figures 13, 14 and 15, while the results of part 2 are summarised in Table 19. The return of the teachers questionnaires was poor for this video and so no references have been made to them.

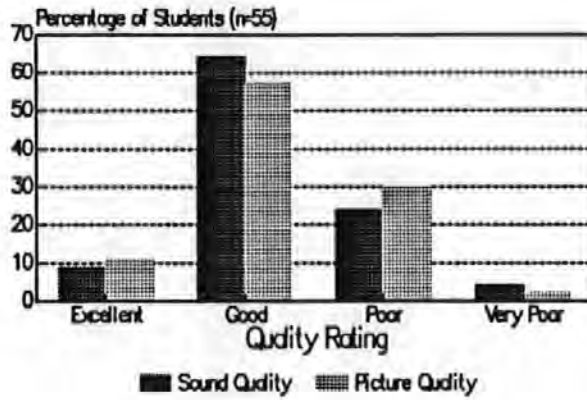


Figure 13 - Student Evaluation of the Sound and Picture Quality

The students' rating of the sound and picture quality was reasonable with 73% of the students rating the sound as good or excellent, and 68% of the students rating the picture quality as good or excellent. These results were confirmed by the students responses to part 2 of the questionnaire which contained few references to either the sound or picture quality.

Student interest in this video was good with 61% of the students finding it either interesting or very interesting. The comments made by the students on part 2 of the questionnaire in response to question 6 suggest reasons for this level of interest. Firstly was the high profile of examples in the video, commented on by 36% of the students. The real examples used throughout the video seem to have caught the majority of students attention. The introductory sequences probably made a substantial contribution. The students also liked the experiments and demonstrations that were used. The animated elephant sequence was popular with some students, but not with others. The good interest level is also reflected in the students' perception of what they had learned from the video, with 58% of the students making positive responses to question 9 of the questionnaire. Many

of these students stated that they had learned that momentum was the product of mass and velocity or simply that they had learned something about momentum.

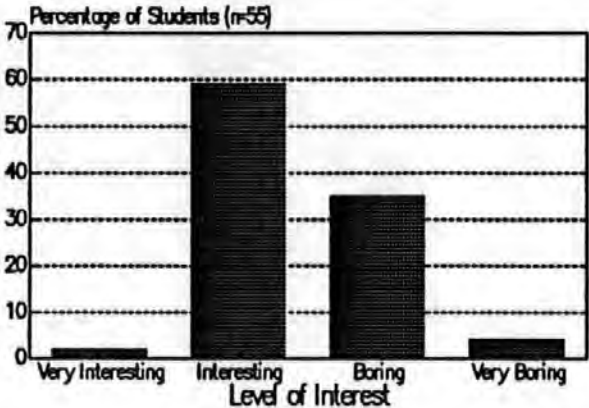


Figure 14 - Student Evaluation of their Interest in the Video

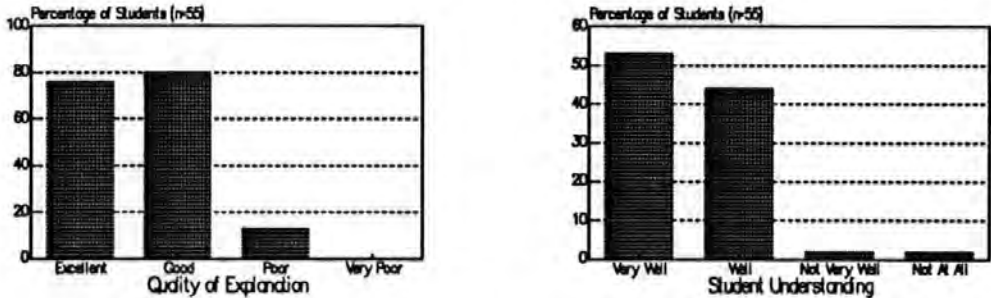


Figure 15 - Student Evaluation of the Explanation and their Level of Understanding

The students' rating of both their understanding of the video and the quality of its explanation were very good. The explanation was rated as either excellent or good by 87% of the students, while 97% of the students felt that they had understood the video either well or very well. The responses to question 9 of part 2 already discussed, illustrated how a high proportion of students feel that they had gained from watching the video, providing further evidence of the quality of

the explanation and the ease with which the students are able to understand the content of the video.

This video clearly has a significant potential for students who are about to be introduced to the concept of momentum. As it is only a pilot video it will never be widely available in its present form, but the reactions of the students are such that it would be well worth producing a refined version. This would be ideal for students following courses that include momentum, but do not extend to conservation of momentum, such as the paper 4 option offered by the Oxford University Delegacy of Local Examinations.

Question 6	Examples Experiments / demonstrations Well explained / easy to understand Elephant sequence Nothing	36% 13% 13% 11% 5%
Question 7	Presenter Experiments / demonstrations Too basic Nothing Elephant sequence Too boring	13% 13% 9% 7% 5% 5%
Question 8	No Presenter Make it more interesting / complicated Experiments / demonstrations Improve quality	29% 13% 7% 7% 5%
Question 9	Momentum = mass x velocity About momentum Nothing / not much Nothing new	29% 29% 11% 9%

Table 19 - Summary of Students' Responses to Part 2 of the Questionnaire

To conclude it would seem that this video would provide an excellent introduction to momentum for students who have not encountered momentum before.

6.2.7 Evaluation of the Video "The Parabolic Path of a Projectile"

This video was seen by 47 students, who were all involved in the experiment at Exeter College. Figures 16, 17 and 18 illustrate the results to part 1 of the questionnaire, while Table 20 summarises the responses to part 2 of the questionnaire. The return of the teachers questionnaires was very poor for this video and so no references have been made to them.

For this video both the sound and the picture quality were rated well. Ratings of excellent or good were given by 83% and 81% of the students for the sound and picture quality respectively.

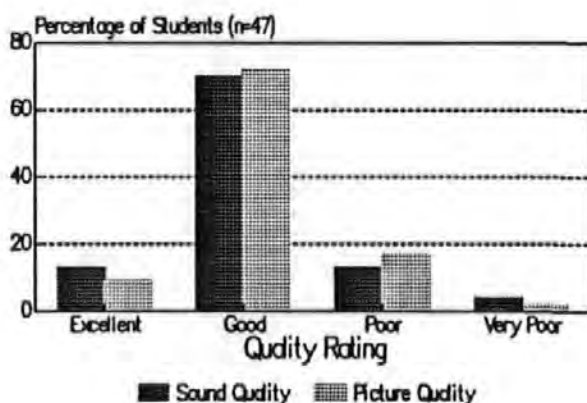


Figure 16 - Student Evaluation of the Sound and Picture Quality

The level of student interest was quite reasonable with 57% of the students stating that the video was interesting or very interesting. The things that the students liked about the video were the experiments on the air table and the examples used. The experiments were very qualitative and supported by small amounts of theory. They were also used to provide slow motion simulations of real motion. This use of an illustrative experiment linked to reality was an effective approach. When answering question 9, 53% of the students made positive statements about what they had learned from the video, indicating that most felt that they had gained by watching it.

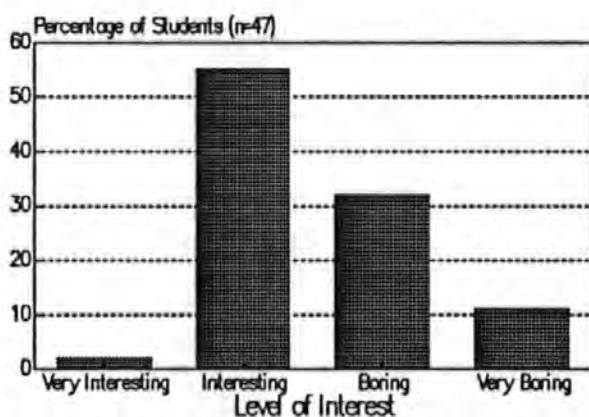


Figure 17 - Student Evaluation of their Interest in the Video

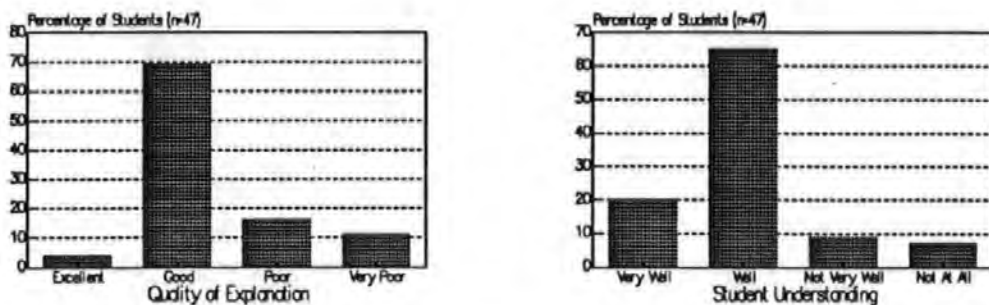


Figure 18 - Student Evaluation of the Explanation and their Level of Understanding

The students were clearly happy with the quality of the explanation with 73% rating it as good or excellent. Similarly 85% of the students felt that they had understood the video either well or very well. There was very little criticism of the explanations given on the video.

This video seems to have a significant potential for use in the classroom, but its major weakness is the presenter and particularly his appearance. Its strength however lies in the demonstrations, linked to reality, that provide visual demonstrations of the ideas of the video. Also of importance was the level at which it was pitched so that the students felt that they understood it well and extended their understanding by watching it.

Question 6	Experiment / use of air pucks Nothing / nothing in particular Examples / real examples Explanation	30% 15% 13% 6%
Question 7	Presenters Nothing / nothing in particular Poor explanation Almost all in studio / no reality Out of date	47% 9% 6% 4% 4%
Question 8	Presenters / presenters appearance No / not really Improve explanation All / most of it	36% 11% 6% 4%
Question 9	About paths of projectiles / projectiles Nothing / not a lot Horizontal / vertical components of acceleration	36% 23% 17%

Table 20 - Summary of Students' Responses to Part 2 of the Questionnaire

6.2.8 Evaluation of the Video "The Optimum Angle"

This video was seen by 47 students, who were all taking part in the experiment at Exeter College. Figures 19, 20 and 21 illustrate the students' responses to part

1 of the questionnaire, while Table 21 summarises their responses to part 2. As the level of return of the teachers' questionnaires was very poor for this video no references are made to their comments.

The ratings given by the students for the sound and picture quality were reasonable. Ratings of good or excellent came from by 59% and 74% of the students for the sound and picture quality respectively. There was no criticism of either the sound or the picture quality in the part 2 responses.

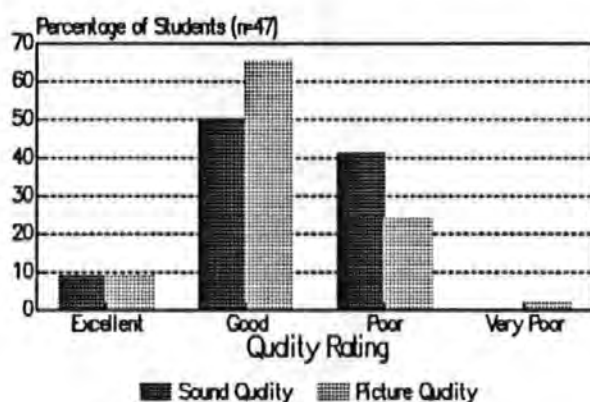


Figure 19 - Student Evaluation of the Sound and Picture Quality

The level of student interest was moderate, with 47% of the students stating that they had either found it interesting or very interesting. The points about the video that the students seemed to like were the demonstrations on the air table and the use of animated paths on a computer. The visual demonstrations appealed to the students. Negative points concerned the calculations and algebra that formed a part of this programme. Some students said that they would like the video to be simpler and easier to understand. These comments suggest that the students find it difficult to follow algebraic manipulation on the screen. In this case the demonstrations seemed to have promoted student interest, while the algebraic manipulation had detracted from it to a certain extent. Again the level

of the video seems to have been about right, as 50% of the students made positive comments about what they had learned from the video.

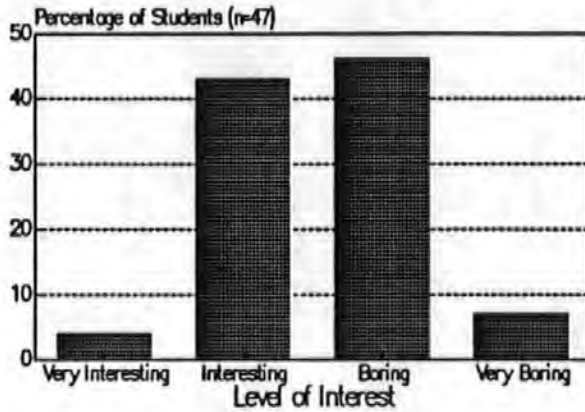


Figure 20 - Student Evaluation of their Interest in the Video

The students' rating of the explanation was reasonable with 66% describing it as excellent or good. They felt that their understanding of the content was good with 77% stating that they understood the video either well or very well. This is also reflected in the students comments for question 9, regarding what they had learned from the video, as mentioned above.

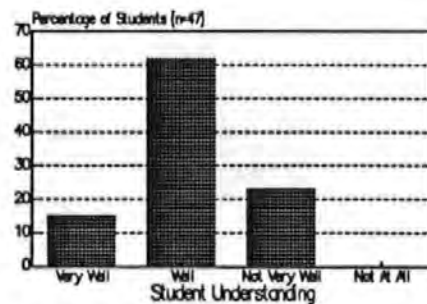
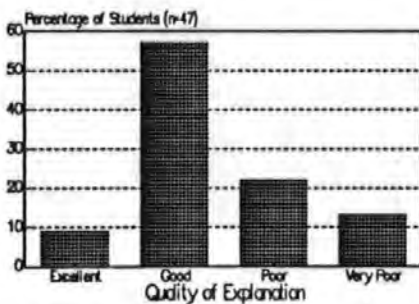


Figure 21 - Student Evaluation of the Explanation on the Video and their Level of Understanding

This video has a potential to be used in the contemporary classroom, as it appeals to a good number of students. However the presenters and their appearance do detract from it, with 35% of the students saying that they would change the presenter, in response to question 8. The main strength of the video lies in its good visual demonstrations, but is marred slightly by the algebra that reduces the students interest.

Question 6	Experiments / Demonstrations Animations of paths Good explanations Nothing / nothing in particular	32% 30% 7% 7%
Question 7	Presenters / appearance of presenters Calculations and use of algebra Poor explanation Out of date Nothing / nothing in particular	30% 13% 9% 4% 4%
Question 8	Presenters / presenters appearance Make it simpler / easier to understand No / not really Update it All of it	35% 17% 11% 4% 4%
Question 9 range	About optimum angle / obtaining the maximum 26% How height of release effects range Nothing / not a lot Maximum range at 45 degrees	 20% 23% 4%

Table 21 - Summary of Students' Responses to Part 2 of the Questionnaire

6.2.9 Evaluation of the Video "Acceleration at Constant Speed"

This video was seen by 40 students, who were all involved in the Exeter College experiment. Their responses to part 1 of the questionnaire are illustrated in Figures 22, 23 and 24, with their comments for part 2 summarised in Table 22. The return of the teachers' questionnaires was very poor, so no references have been made to their comments.

The students' rating of the sound and picture quality were both very good. For the sound 85% of the students rated the quality as either excellent or good and 88% of the students rated the picture quality in the same way. These results should not be surprising for a video that has been recorded off-air from a recent broadcast.

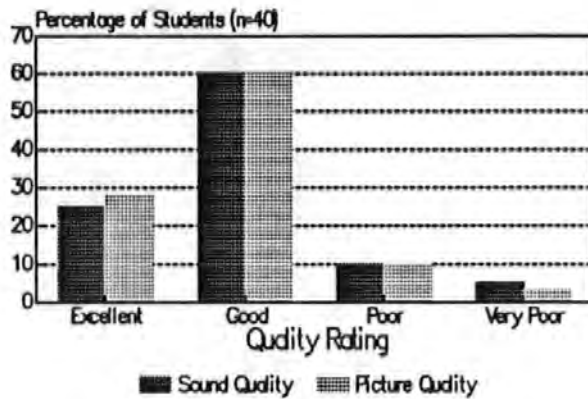


Figure 22 - Student Evaluation of the Sound and Picture Quality

Student interest in this video was poor with 68% of the students describing it as either boring or very boring. This is quite alarming because this is a relatively recent OU production. Examining the students responses to part 2 of the questionnaire indicates some possible reasons for this. In response to question 7 48% of the students stated that they did not like the explanation given on the video, in particular some referred to calculations and the use of formulae. The responses to question 8 suggested that the students would like to see changes to the explanation and the use of less calculations or formulae. Both these types of comments suggest that there was too much algebraic manipulation in the video and that it was probably at too high a level for many of the A-level students.

The other factors that emerged that could account for the low interest were the use of a presenter and the length of the video. As with almost all the other videos that used on screen presenters there was a fair degree of criticism of the presenter. In addition 15% of the students stated that they disliked the length of the video. This was in fact a full, un-edited OU production of 24 minutes length, which was probably too long for many of the students.

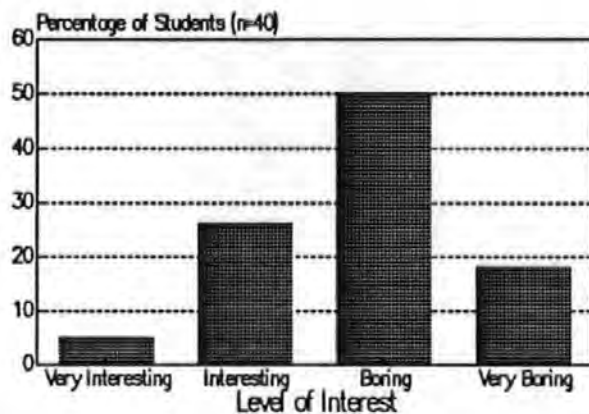


Figure 23 - Student Evaluation of their Interest in the Video

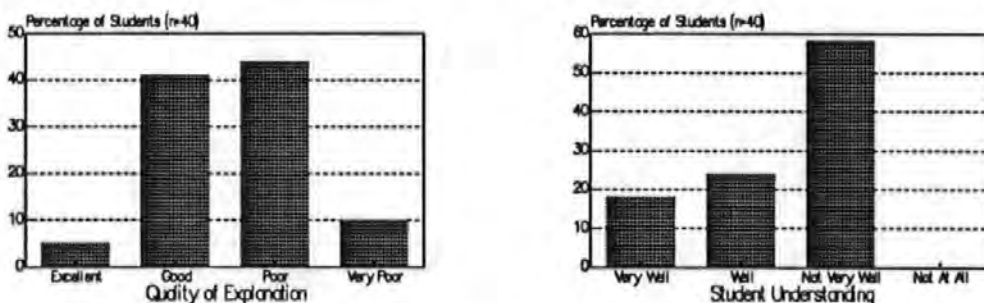


Figure 24 - Student evaluation of the explanation on the Video and their Level of Understanding

The students' rating of the quality of the explanation on the video was poor with 54% of the students stating that they found it either poor or very poor. The quantity and level of the algebraic manipulation included probably account for

this, and also for the low level of student understanding. 58% of the students stated they had not understood the video very well. Both the poor explanation and poor understanding of the video are reflected in the students' perception of what they have learned from the video. In response to question 9, 40% of the students stated that they had learned nothing or very little from the video.

Question 6	Examples Red Arrows Space station Nothing / not much Good diagrams Presenter	23% 15% 13% 8% 5% 5%
Question 7	Explanations Presenters Too long / too much at once Switching presenters Too complicated Use of formulae / calculations All of it	48% 15% 15% 5% 5% 5% 5%
Question 8	No Presenters Improve explanations Everything Use of calculations / formulae Too long Less complicated / easier to understand	15% 15% 15% 13% 10% 8% 5%
Question 9	Nothing / not a lot Acceleration = v^2/r About circular motion Acceleration is towards the centre	40% 15% 13% 8%

Table 22 - Summary of the Students Responses to Part 2 of the Questionnaire

Clearly this video is not very suitable for use with A-level students as it is too long and contains too much algebraic manipulation which is at too high a level. There were some good points about the video that did emerge from the students comments. The students did like the examples used in the video with 51% making reference to these. Particularly popular were the Red Arrows and the space station examples.

6.3 The Formulation and Application of a Model for Video Production

6.3.1 Introduction

This section describes how the responses to the video evaluation questionnaires were used to formulate for the first time a research based model for video production for topics in mechanics. At the time that this model was being developed the CTM was asked to produce two video programmes for the new SMP A-level, Mathematics 16-19. This provided an ideal opportunity to make use of this new model in the design and production of these two video programmes. In addition to the formulation of the model this section also describes how it was applied to the development of the videos "Motion" and "Momentum and Collisions".

6.3.2 A Research Based Model for Video Production

As the students' questionnaires were analysed the responses could be broadly categorised as either positive or negative criticism. In each of these categories there were a number of aspects that emerged for more than just one video. By examining these comments it has been possible to formulate the model that is described below.

The aspects of the videos that were repeatedly the subjects of negative criticism are listed below;

(i) The presenter. There were very few videos where the presenter was not criticised, including those videos which used a voice-over rather than an on-screen presenter.

(ii) Algebraic manipulation and extensive calculations. Not all the videos used in the experiment contained this feature, but all those that did received a good deal of criticism of it. The videos "The Optimum Angle" and "Acceleration at Constant Speed" contained sequences of this type.

(iii) Lack of reality. This point emerged particularly in the videos "The Parabolic Path" and " $F=ma$: Newton's Second Law", where extensive studio sequences were used with very few real examples. In some cases students also referred to the lack of interesting examples.

(iv) The level of the video. Where students had felt that the video was pitched at an ability level that was too low there had been many comments from the students. They feel that their intelligence has been insulted by the video. Also the level of the video should not be too high, as for example was the case in the video "Acceleration at Constant Speed" where many students failed to follow the algebraic manipulation.

(v) The length of the video. In the case of the video "Acceleration at Constant Speed" the video was clearly too long, presenting too many ideas for the students to take in.

There were also positive comments made by the students about the videos that they had watched. These have been summarised in the sections listed below.

(i) The use of real examples. All the videos that made good use of examples of real situations, were praised for doing so. Videos such as "What is a Force ?" and "Newton's First Law" were strong in this respect. Many of the examples in

these videos were the focus of discussion, which seems to have been an approach liked by the students.

(ii) The use of visual demonstrations. In videos such as "Action and Reaction" and "The Parabolic Path of a Projectile" the demonstrations that were used to illustrate the ideas being considered greatly helped the students and were well received.

(iii) Clear simple explanations. The videos that featured clear simple explanations were appreciated by the students, particularly when they were uncluttered by including algebraic manipulations.

Bringing these factors together it has been possible to formulate a model for the production of video resources for the teaching of mechanics. It includes the factors that have been described as being helpful above and avoids those that have provoked negative reactions from the students. In addition it suggests a potential format for a video and gives guide-lines that should be adhered to throughout the video.

The general guide-lines are listed below:

(i) A presenter should not be used on the video. A good commentary is better, with a voice that does not have any strong accents.

(ii) There should be very little or no use of algebraic manipulation on the video. It is better to leave this for the teacher to develop after the video. It may however be useful to include suggestions in the supporting notes for the teacher to follow up after viewing. The teacher will be able to match this sort of work much more

closely to the students abilities, rather than boring the more able students or losing the weaker students while using the video.

(iii) Where it is necessary to use people in the video, try to find students similar to those of the target audience and avoid extremes of fashion, so as not to cause the video to age prematurely.

(iv) Make use wherever possible of visual demonstrations to communicate ideas and concepts. There are many demonstrations that can be reproduced on video that it would be impossible for teachers to carry out in a classroom.

(v) Throughout the video make use of real examples to indicate the relevance of the topic under consideration and the applications of the theory. Studio mock ups are not sufficient unless backed up by the real examples that they simulate.

(vi) Ensure that the video is pitched at a level that is appropriate for the target audience.

(vii) Carefully monitor the length of the video. It should be long enough for the students to feel that it has been worth watching, but not so long that they are unable to take in all the ideas that it presents. It may be better to produce two short videos rather than one that is too long.

By careful consideration of the guide-lines listed above and the aspects of video that caused a negative reaction among the students, it was possible to propose a framework for the production of mechanics video resources. In addition to following this framework the guide-lines listed above should be adhered to. The framework consists of six phases which are described below.

Phase 1 - A fast moving introduction based on real situations that relate to the theory that is to be developed. The aim of this introduction is to arouse the students' interest and to set a scene from which the theory can be developed.

Phase 2 - Developing the theory from real examples, probably taking the form of a discussion of real situations. This will both introduce the area of study and justify doing so.

Phase 3 - The introduction of other real examples that illustrate the theory considered so far and possibly indicate where it needs to be extended or how it relates to other associated theory.

Phase 4 - Extension of the theory or development of associated theory. This phase may well include the presentation and analysis of data on the video, as well as possibly indicating some follow up activities.

Phase 5 - A closing sequence of real examples related to the theory that has been developed. This may well include sequences that have been discussed as part of the video.

Phase 6 - Problems for the students. This would pose problems for the students to consider after the video. These problems would either present data or situations for analysis, or alternatively give discussion starters based on real examples.

Note that it would be possible to interchange phases 5 and 6 if this was felt to be appropriate. Also phases 3 and 4 may be repeated in order to allow a progression through the required material.

It is anticipated that videos produced using these guide-lines and this framework would promote a greater level of student interest than the existing video resources and thereby achieve improved student understanding.

6.3.3 Application of the Model to the "Motion" Video

The content of this video was specified by SMP, but there was still considerable freedom for the style and presentation of the video to be developed along the lines of the above model. The specifications related very much to the level of the video and the content. The aims of the video were to discuss the modelling aspects of describing motion and to provide real data for analysis.

As a general point it was decided at the outset that a voice-over technique would be used and that no presenter would be used on the video. A professional voice was considered, but due to budget restrictions one of the staff of the CTM was used for this purpose.

Each phase of the video is described below, showing how it matches the phases in the model.

Phase 1 - A fast moving introduction is presented, giving many examples of motion in reality including aeroplanes, a jetski and finishing with a parachute display and a rocket taking off. These examples present cases where the motion would be easy to model and others where it would be very much more difficult.

Phase 2 - This takes up the motion of the parachutist, who rotates in quite a complicated manner as he falls to the ground. This is contrasted with the simple straight line motion of an ice hockey puck between hits. The idea of modelling objects as particles is then developed as these examples are discussed.

Phase 3 - The particle model is then applied to a sprinter and the assumptions made in using this model are stated. The motion of the sprinter is then considered and the times at which she passes markers on the track are recorded for use in phase 4.

Phase 4 - The data collected as the sprinter ran is plotted on a graph to provide an example of the way in which data can be analysed. A student is shown finding the gradient of a part of the graph and this is compared with the average speed.

As stated in the model there are occasions when it may be appropriate to interchange phases 5 and 6, and this was considered to be one.

Phase 6 - Two further situations are then presented, first a swimmer diving into a pool and swimming one length and second a motorbike passing a number of equally spaced cones. The times for both these examples were recorded by the students as the video progressed. After the video they were expected to plot the data they had obtained and to discuss the motion they had seen and the implications of modelling it.

Phase 5 - At the close of the video were a number of sequences providing further examples of motion. At the beginning of these the students were invited to consider the suitability of the straight line particle model for each example and if it was inappropriate to suggest an alternative.

6.3.4 Application of the Model to the "Momentum and Collisions" Video

As with the "Motion" video the content of the "Momentum and Collisions" video was specified by SMP, but the production was then left in the hands of the staff of the CTM. The video was subject to certain constraints as it had to fit into the Mathematics 16-19 course at a point selected by SMP. The aim of the video was to show that momentum is an important concept in mechanics because it is conserved in collisions.

An approach not using a presenter was also adopted for this video with a voice over being used as for the "Motion" video. Each phase of the video is now described below.

Phase 1 - A fast moving introduction is used to begin the video. All of the introductory sequences featured collisions in a variety of real situations, including car crashes, ten pin bowling and others.

Phase 2 - This phase of the video discusses various examples in order to identify the important factors that affect the outcome of a collision. First this concentrates on the speed of the bodies involved in a collision, using as an example the collision between fast and slow moving balls and skittles at a bowling alley. The commentary draws out the difference in results for balls moving at different speeds. The video then moves on to consider the importance of the mass of the bodies by using a head on collision between a lorry and a car.

Phase 3 - As all the examples considered in phase 2 had concentrated on direct collisions real examples are now used to illustrate the fact that not all collisions

are direct and some are oblique. A collision between two snooker balls is one of the examples used.

Phase 4 - Here the main theory is developed, initially from the snooker collision and then from an experiment using two pucks of different masses. The velocities of the balls and the pucks are represented using arrows that are moved around the screen to illustrate the principle of conservation of momentum. The snooker collision is brought in as a real example and the pucks as an extension of this example. Once the result has been identified there is a short summary of it.

Phase 5 - The video closes with a number of short clips showing examples of collisions that were used during the video itself.

Phase 6 - At the end of the video 4 problems were posed concerning momentum and collisions. Each is based on a real example and the problem stated on the video, with a "stop the tape" caption inserted between each problem. The problems were backed up with written materials that contained any data required and also the problem statement.

6.4 The Evaluation and Revision of the SMP Videos

6.4.1 Evaluation of the Video "Motion"

This video was seen by 343 students, most of whom were following the new SMP Mathematics 16-19 course, but also other students from other schools and colleges. The results for part 1 of the questionnaire are recorded in Figures 25, 26 and 27, while the comments from part 2 are summarised in Table 23.

The students' overall ratings of the sound and picture quality for this video were fairly good, with 69% and 61% of the students rating the sound and picture quality as either excellent or good respectively. However some students stated that they had found these aspects of the video poor and would like to see them improved, with 6% of the students giving the later response to question 8. An examination of the responses on a school by school basis revealed that there were several schools where a very high proportion of the students gave poor ratings of the sound and picture quality. This suggests that in some schools poor play-back equipment may have been used and that this was reflected in the students responses from that school. The teachers who completed questionnaires also rated the sound and picture quality as good to fair.

Student interest in the video was reasonable, with 58% of the students stating that they found it interesting or very interesting, but not as good as had been anticipated. While a few of the teachers felt that student interest was high, the majority felt that it was best rated as fair, confirming the responses given by the students themselves.

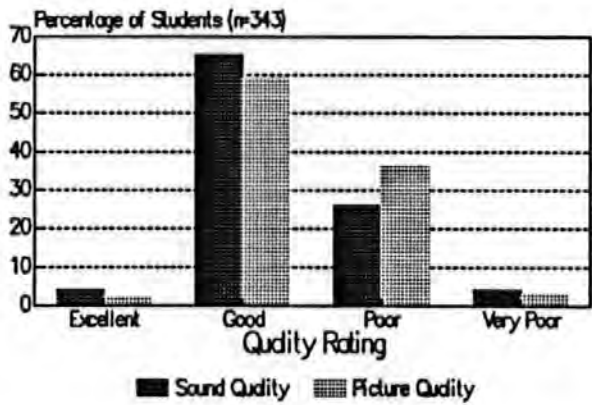


Figure 25 - Student Evaluation of the Sound and Picture Quality

Part 2 of the questionnaire revealed two reasons that probably account for the lower than anticipated level of student interest. These were associated with the presentation of data on the video and the level at which it was pitched. The first problem was noted by 26% of the students who wanted to improve the quality of the text or display it for longer, in order to make it easier to record. Some suggestions were made such as using a plain background or giving the students more time to prepare for the activity. There was also an error in the data for the motorbike example, which 17% of the students said that they would like to see corrected. The second problem concerned the level of the video, with 15% of the students stating that they felt that it was aimed at too low a level for sixth form students. These students seemed to think that the video only touched the surface of modelling and would have been better used if it took these ideas further instead of collecting data for graph drawing, with which many of the students were already familiar. The fact that 41% of the students felt that they had learned little or nothing from the video provides further evidence to support this claim.

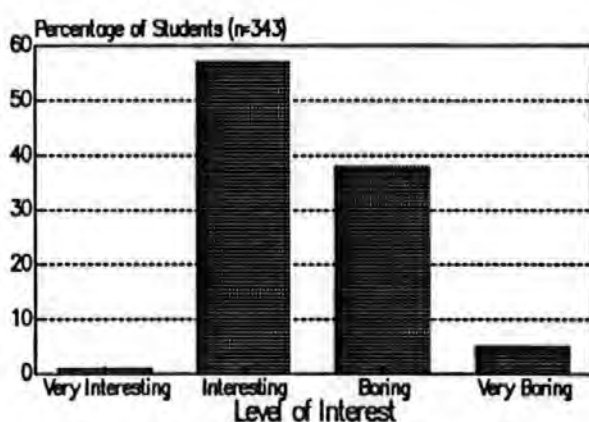


Figure 26 - Student Evaluation of their Interest in the Video

However there were a good number of points about the video that went down well with the students, as can be seen from their responses to question 6. They clearly liked the variety of examples included and the explanations given, which had been based on a discussion of the examples used. The approach seems to have been successful, with the level of the content being the weakest aspect.

The students ratings of the quality of the explanation and their understanding of the video were good. With regard to the quality of the explanation 67% felt that it was either good or excellent and 94% stated they had understood it well or very well.

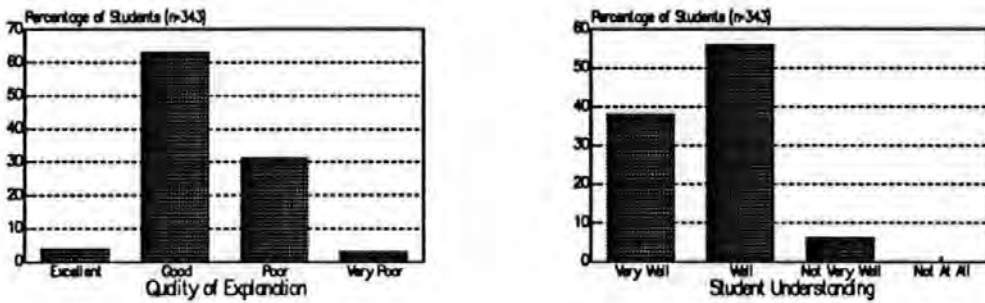


Figure 27 - Student Evaluation of the explanation on the Video and their Level of Understanding

From the students' responses it can be seen that the first of the new videos produced using the research based model had prompted a reasonable level of student interest, but had been pitched at too low a level. The actual level of the content of the video had been clearly defined by SMP at the outset of the project and so in this aspect there was no room for manoeuvre. Of the aspects that could be controlled at the production stage there were two possible areas for improvement. The first of these was with regard to the commentary. Moving away from a presenter had produced a much lower level of presenter criticism, but 12 % of the students still did not like the voice of the presenter. The other

aspect concerned the actual physical process of data collection by the students as part of the video.

Question 6	Music The examples Sports examples Well explained / easy to understand Aeroplane examples Related to real life Variety of types of motion	18% 17% 15% 12% 9% 6% 6%
Question 7	Music / monotonous music Text difficult to read / copy Approach too elementary Mistake in data for motorbike Commentator's voice Poor picture / sound Examples	23% 22% 15% 14% 12% 8% 4%
Question 8	Display data better Correct motorbike data Aim at a higher level Change commentator Improve sound / picture quality Nothing / not really	26% 17% 15% 7% 6% 4%
Question 9	Nothing / not much Nothing new About models / modelling Use of particles Reinforced existing ideas	31% 10% 7% 5% 4%

Table 23 - Summary of Students' Responses to Part 2 of the Questionnaire

Thus in conclusion this video based on the research model has interested and stimulated a much greater proportion of the students who have watched it, having much less negative criticism, most of which were generated by the content specifications rather than the design and production of the video. The video has a place in the classroom, but probably for use with students who have experienced a limited study of motion at GCSE level.

6.4.2 Evaluation of the Video "Momentum and Collisions"

This video was seen by 288 students, most of whom were following the new SMP Mathematics 16-19 course, but also of students from other schools and colleges. The results for part 1 of the questionnaire are recorded in Figures 28, 29 and 30, while the comments from part 2 are summarised in Table 24.

The students' rating of the sound and picture quality were good for this video with 77% and 75% of the sample stating that the sound and picture quality were good or excellent respectively. There were also very few comments about poor sound or picture quality in the part 2 responses.

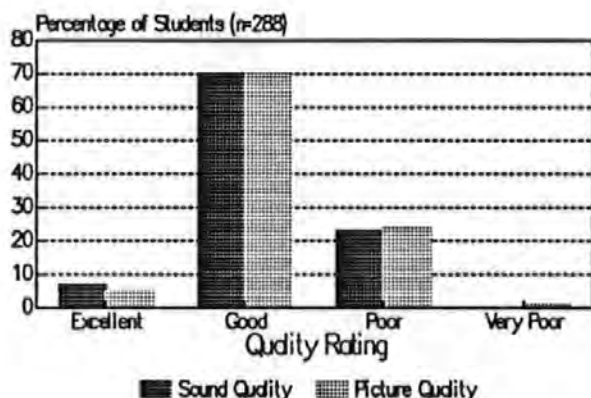


Figure 28 - Student Evaluation of the Sound and Picture Quality

Student interest was high in this video, with 69% of the students reporting that they found it interesting or very interesting. The teachers described the students interest as fair to high. This level of interest was better than that for the "Motion" video and more in line with the expectations for a video based on the model described in section 6.3.2. The reasons for the good interest level can be found in the responses to part 2 of the questionnaire. Here over 50% of the students referred to the examples used to illustrate the video and that formed the focus for

discussion on the video. They also referred to the explanatory diagrams and the easy to understand explanations. It was also possible to identify potential ways of raising student interest further. This could possibly have been achieved by pitching the video at a higher level, but this would have been outside the brief and may well have lost some students.

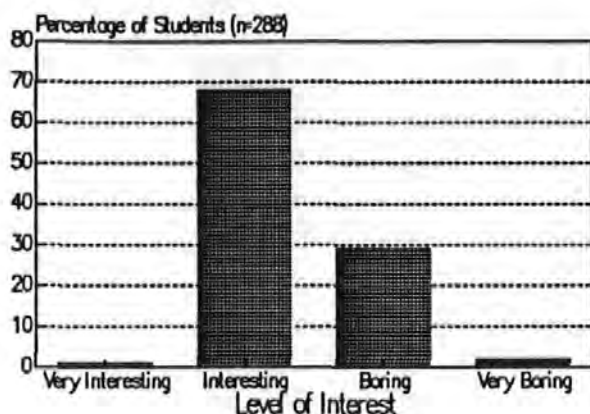


Figure 29 - Student Evaluation of their Interest in the Video

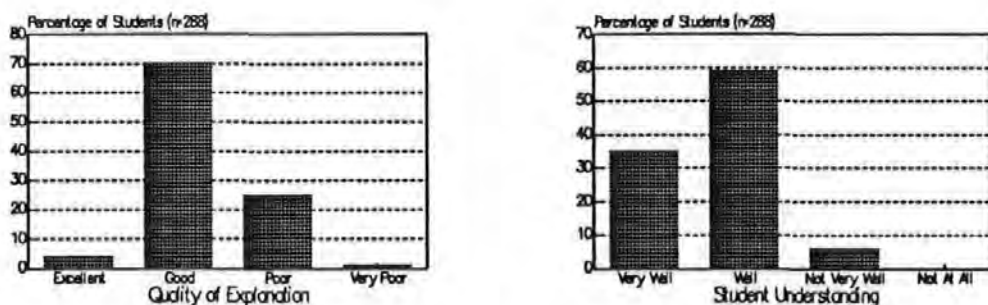


Figure 30 - Student Evaluation of the Explanation on the Video and their Level of Understanding

The quality of the explanation and the student understanding of the video were pleasing. The explanation was rated as good or excellent by 74% of the students and 94% had said that they had understood it either well or very well. This again is pleasing and probably due to the absence of algebraic manipulation and a

concentration on discussion and visual explanation. It was disappointing that 32% of the students felt that they had not learned anything from the video, but the teachers had reported that it was aimed at the right level for their students. It may be that some students have already encountered conservation of momentum in their science studies.

Question 6	Examples / good examples Car crashes Explanatory diagrams Well explained / easy to understand Music	27% 24% 9% 8% 7%
Question 7	Music Narrator Content too basic Problems doing exercises Too short Flashing text Poor picture / sound Nothing / not much	24% 13% 9% 9% 6% 6% 5% 4%
Question 8	Change music More / deeper explanations Nothing / not really Change commentator Remove flashing text	21% 14% 14% 13% 4%
Question 9	Nothing / not much Momentum is conserved About momentum Momentum is mass times velocity Reinforced existing ideas	32% 14% 14% 8% 7%

Table 24 - Summary of Students' Responses to Part 2 of the Questionnaire

There were a few general problems that emerged from the students responses. It is interesting to note that there is still a fair amount of criticism of the narrator, with 13% of the students stating that they would like the voice changed. Also of concern were some aspects of the problems set at the end of the video. In several cases the timing of the instructions was poor making it difficult for the students to note the required features of the problem. Also the level of the video was again a problem, which seems to stem from the overlap of physics and

mathematics syllabi. It is important to concentrate on the basic concepts for those students who have not taken physics, but this may not be as appropriate for those students who have studied physics.

Thus this video seems to have captured the interest of a high proportion of the students through its mix of interesting real examples, discussion of these examples and visual explanations. The vast majority of the teachers who used it found it helpful and intended making further use of it in the future.

6.4.3 Re-editing the SMP Videos

As the two videos, "Motion" and "Momentum and Collisions" were intended as pilot productions they were duly revised in the light of the outcome of the evaluation exercise. There were some general points that applied to both videos while others applied to specific aspects of each video. The major change to both videos was the use of a professional voice. A local radio presenter was used to produce the commentary. It was interesting to note that he was also able to make some minor changes to the script where the original wording could be changed to improve the flow of the words. Also a better quality graphics generator was employed.

There were few changes to the "Motion" video other than the general ones described above. The main change was not asking the students to record the data as it appeared on the screen, instead the data was presented and also provided on the worksheets. It was hoped that this and the improved graphics would remove many of the students complaints. The flashing graphics were also replaced by more conventional text. Other than this there were minor changes to the script. A major change raising the level of the content had been considered but this was not acceptable to SMP. However they did decide that it may not be appropriate

for all students to watch the video; It would depend on the background of their GCSE studies.

The changes to the "Momentum and Collisions" video were also mainly the general ones described above. As for "Motion" the text used was improved and flashing text was also replaced. The ten pin bowling sequence was replaced by a sequence using mallets hitting tent pegs at different speeds and two other slightly ambiguous sequences were removed. Otherwise all the changes were to the script. The most drastic of these was a revision of the instructions for the problems, so that it would be easier for the students to note the relevant features of the problems. Also the explanation covering the manipulation of the vectors to show the conservation of momentum was expanded.

The changes to both videos did not need to be that great, as the pilot versions were certainly satisfactory. However it was anticipated that these changes would improve the reactions of students to the videos.

6.4.4 Evaluation of the Revised Version of the Video "Motion"

This video was seen by 60 students, none of whom were involved with the SMP 16-19 Mathematics scheme. The results for part 1 of the questionnaire are recorded in Figures 31, 32 and 33, while the results for part 2 are summarised in Table 25.

For the revised video the ratings of the sound and picture quality were given as excellent or good by 94% and 90% of the students respectively. These figures are better than those for the original video, which also were fairly good. There were no comments about poor sound or picture quality that were made for the

original version. These figures add weight to the argument that some of the negative reaction to the sound and picture quality of the original could be attributed to the use of poor play-back equipment.

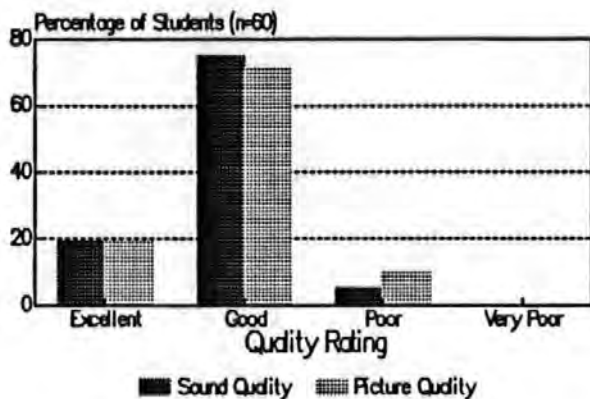


Figure 31 - Student Evaluation of the Sound and Picture Quality

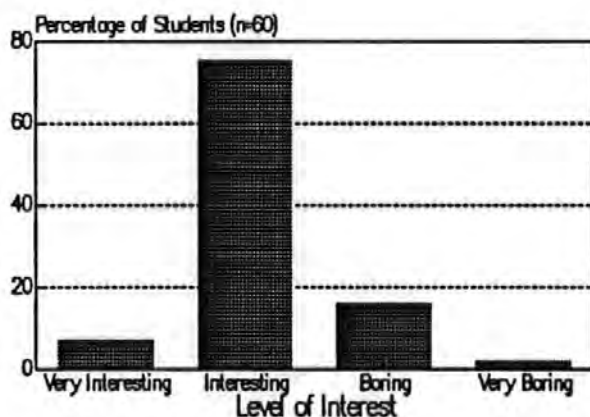


Figure 32 - Student Evaluation of their Interest in the Video

The figures for student interest were very encouraging with 82% of the students, describing the video as either interesting or very interesting. This is a greater proportion than for the original version. The two factors that had been identified in Section 6.4.1 as possibly contributing to a level of student interest that was

lower than anticipated were not evident here. The problems with data collection had been completely removed during the re-editing. The problems due to the level had also not emerged with the revised version. It is possible that it was the actual process of collecting data from the video that was partly responsible for the students reaction that the video was at too low a level. The proportion of students stating that they had not learned anything from the video had also been reduced from 41% for the original to 25% for the revised version, indicating again that the video now seemed to be at a more appropriate level. In addition the number of students who felt that they had learned something about the particle model increased from 12% to 22%. Not actually recording the data from the videos may have shifted the emphasis of the video more towards the particle model. As with the original version the students clearly liked the examples and the explanation given, both of which would contribute to student interest.

The students rating of the explanation on the revised video was very similar to that for the original. Their rating of their understanding of the video was not as good for the revised version. For the revised version 76% of the students stated that they had understood it either well or very well compared with 94% for the original version. There do not seem to any reasons emerging for this in the responses to part 2 of the questionnaire, but it could be that the ideas in the video seemed more difficult now that the emphasis had been taken off the process of data collection. It may be that the data collection approach originally used trivialised the video.

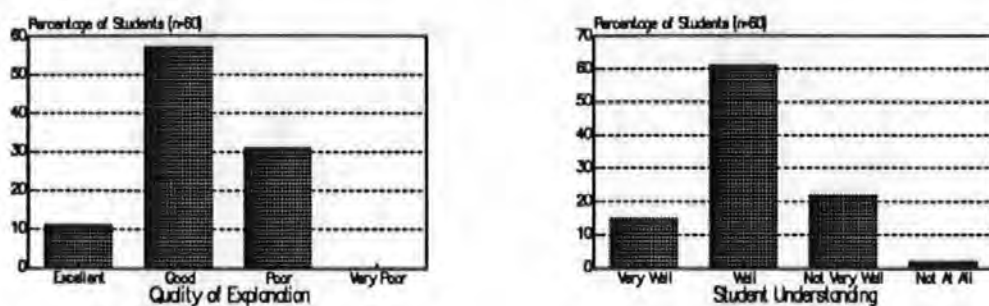


Figure 33 - Student Evaluation of the Explanation on the Video and their Level of Understanding

The other main factor that had been criticised in the original video was the presenter's voice, but in this revised version there was no criticism at all of the presenter. Criticism of the explanation and the music has risen slightly, probably due to that fact that there were now less glaring problems with the video.

Question 6	The examples The music Good / understandable explanations Pictures / diagrams	38% 20% 13% 10%
Question 7	Music Explanation Too short Nothing / not much	38% 12% 8% 5%
Question 8	Change music Improve explanation No / nothing Make it longer	25% 18% 12% 5%
Question 9	Nothing / not a lot About modelling with particles About motion There are different types of motion	25% 22% 13% 7%

Table 25 - Summary of the Students' Responses to Part 2 of the Questionnaire

In conclusion it would seem that the re-editing process was worthwhile as it produced a video that was better received. The use of a professional voice was

clearly of great benefit. Also the removal of the data collection process seems to have raised the level of student interest in the video. It certainly has raised the possible danger of trivialising a video by the use of excessive data collection.

6.4.5 Evaluation of the Revised Version of the Video "Momentum and Collisions"

This video was seen by a total of 66 students none of whom were involved in the SMP 16-19 Mathematics scheme. The results for part 1 of the questionnaire are recorded in Figures 34, 35 and 36, while the results for part 2 are summarised in Table 26.

For this revised video the sound and picture quality were rated as excellent or good by 94% and 95% of the students respectively. These figures are better than for the original version and lend further weight to the argument that some of the schools using the video in the trials had poor quality play-back equipment.

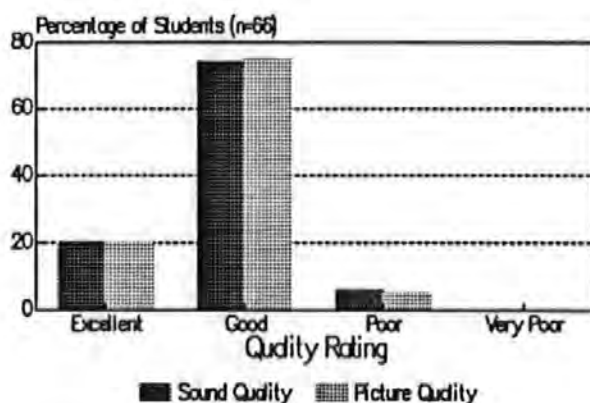


Figure 34 - Student Evaluation of the Sound and Picture Quality

Student interest in the revised video was very high with 97% of the students stating that they had found it either interesting or very interesting. This was

higher than for the original version of the video. Again the students said that they liked the examples used and the vector diagrams. The proportion of students referring to the diagrams was greater than for the original. Slowing down the pace and increasing the explanation at this stage of the video seems to have been helpful.

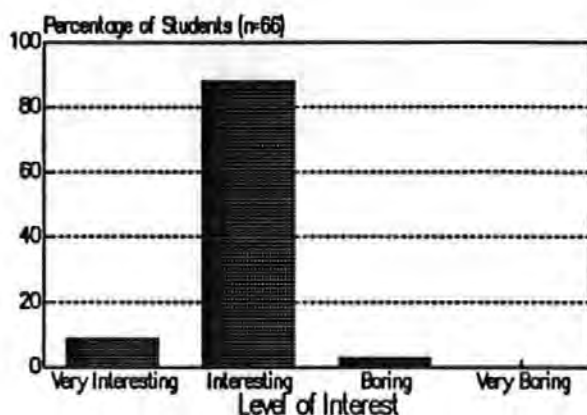


Figure 35 - Student Evaluation of their Interest in the Video

The students' rating of their understanding of the video was very similar to those for the original, with the rating of the explanation slightly better. The understanding of the video was rated as very well or well by 90% of the students for the revised video compared with 94% for the original. For the quality of the explanation 89% rated it as either good or very good compared with 74% on the original. This improvement again points possibly to the changes made by the vector manipulation sequences. It was also interesting to note that there were less negative responses to question 9, with only 8% of the students stating that they had learned little or nothing from the video.

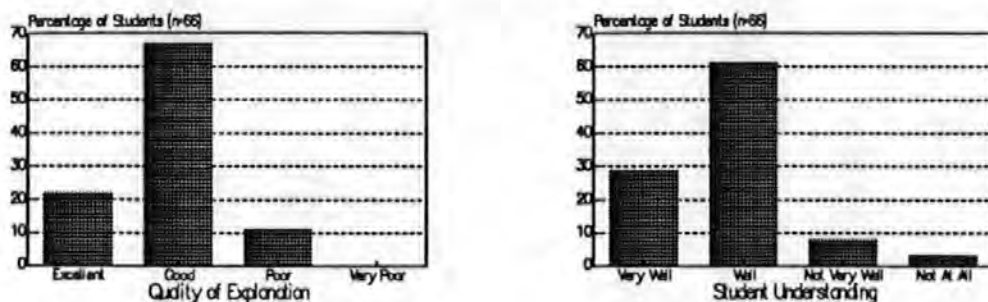


Figure 36 - Student Evaluation of the Explanation on the Video and their Level of Understanding

Question 6	Animations / diagrams Examples / Seeing Collisions Crashes Music Concise / to the point Clear / simple explanation Everyday / realistic examples	20% 18% 12% 11% 9% 9% 5%
Question 7	Music Too short Commentary too fast Brief Explanations Silent bits Very basic / too simple	26% 12% 6% 5% 5% 5%
Question 8	No / not much Make it longer Change music More / more detailed explanations	21% 12% 12% 8%
Question 9	About momentum Momentum = mass x velocity Momentum and Vectors Direction of momentum important Nothing / not a lot Conservation of momentum Reinforced existing ideas Applications of momentum	21% 15% 10% 8% 8% 8% 8% 6%

Table 26 - Summary of the Students' Responses to Part 2 of the Questionnaire

In conclusion this video seems to have benefited mildly from the re-editing process, but it has also confirmed some of the suggestions made about video design. The correct pace and level of delivery have led to improvements in

student learning and understanding. In addition, the use of a professional voice has removed all traces of criticism of the presenter. This video has benefited from re-editing, but not to the same extent as the "Motion" video. A video with the degree of success achieved by the pilot version of "Momentum and Collisions" would not normally justify re-editing, but in this case it was worthwhile to see the affects of small changes to the content, voice and pace.

6.5 Conclusions

The work reported in this chapter identifies two main needs that should be satisfied if effective video resources are to be produced. The first is the need for the videos to be designed so that the target audience is able to relate and learn from them. The second is the need for pilot productions and thorough evaluation of these pilots before large-scale distribution.

This chapter has identified a new model that will lead to the production of video resources that A-level mathematics students will relate to when studying mechanics. Although it has been formulated for this particular target audience many of its features will be transferable to other similar subject areas. It does offer an approach geared towards mechanics, but this could be applied to almost any area within mathematics or science, while some of the more general guidelines could well be applied in other more diverse subjects. This model would certainly provide, for the first time, a basis on which videos for other areas of science or mathematics could be developed. Producers of such resources could then investigate how these could be applied to their subject and possibly include some evaluation of existing resources.

The production and subsequent evaluation of the SMP videos has clearly shown the importance of a pilot production. There were several deficiencies in the

"Motion" video in particular that were eliminated as a result of the evaluation results. In the case of "Momentum and Collision" the need for revision was less evident, but some important modifications were made as a direct result of the evaluation exercise. The effectiveness of the final versions of these two videos would not have been as great without the insights gained from the pilot work. If there is an instance where a video is to use new techniques or include student activities based on the video there is a real need for a pilot production and its evaluation with real students. A similar conclusion was reached by Salkeld (1982) after he was involved in the production of a series of programmes that were modified significantly after a series of pilots had been evaluated.

The results of the evaluation of the pilots also validated the model formulated in section 6.3.2. It left no doubts that the model would be effective and the conclusions reached from the results and implemented in the re-editing process, served to emphasise points of the model further. In particular the use of a professional voice was picked up from the evaluation results.

In addition to identifying criteria that need to be satisfied by video productions this chapter has also provided the only report on the quality of the videos that are currently available for use in mechanics teaching. As was said in chapter 3 there are very few video resources that have been designed specifically for use with A-level students, some have been adapted for them, but most were originally aimed at a different audience. The reactions of the students to the videos that have been evaluated in this experiment suggest that, while many of the videos that have content that relates to A-level mechanics, very few have an approach that relates to A-level students. The videos that were well received were the ones which incorporated some of the factors that feature in the model. Those that took approaches that were at considerable variance with the model received a very poor reaction from the students. So in addition to the need identified in chapter 3

for more video resources to cover other aspects of mechanics there is also a need for new productions to replace those that already cover the mechanics, but do not relate to the students.

Chapter 7 - Results of the Experiment

7.1 Introduction

This chapter presents the analysis of the numerical data obtained from the experiment. These results include the background information and pre-test results as well as the results for the various post-tests. The background data and the pre-test scores are dealt with first in section 7.2 and then each of the topics covered by the video teaching package are reported on in subsequent sections. Where a post-test contained questions on more than one topic area there are separate sections to deal with each of these topics. This arises in several cases as the timetables of the teaching varied in the two years of the experiment and different topics were grouped together on different occasions.

At several stages of the work statistical tests were used to determine whether any significant differences existed between the experimental and control groups. Where such tests were used the following procedure was followed.

(i) The two non-video groups were first compared to check that there were no statistically significant differences between them. The two video groups were then compared in the same way. This step was included to ensure that the data being pooled at stage (ii) was from groups that could be considered to be equivalent.

(ii) The results from the two non-video groups were then pooled and from then on treated as a single group. The two video groups were also combined in the same way.

(iii) The results of the two groups formed by step (ii) were compared to test for significant differences in the performance of the video and non-video groups.

Two problems that emerged during the experiment were;

(i) That some students had missed a significant part of the video input.

(ii) That some students had left the course and would no longer be taking part in the experiment.

Problem (i) clearly means that not all of the students had seen the videos and therefore their tests scores could not be included in the analysis. This in conjunction with problem (ii) means that both experimental and control groups have had their constitution changed, which implies that the new groups may not have been equivalent at the outset of the experiment. Where these problems have affected the groups their initial equivalence has been re-established before the analysis of the results proceeded.

7.2 Analysis of the Background Information Questionnaire and the Pre-test Results

7.2.1 Details of Analysis

The purpose of the analysis of the data given by the background questionnaire and the pre-test was to assess the equivalence of the experimental and control groups participating in the experiment. The background questionnaire would provide information about the constitution of the groups and the students' general academic ability while the pre-test would look at their initial understanding of mechanics. A decision could then be taken as to whether there

was sufficient evidence to support the assumption that the experimental and control groups were equivalent.

The data from the background questionnaires was collated from the individual questionnaires and recorded in tables that presented the data for each individual group and for the video and non-video groups formed when they were combined. This process allowed comparisons to be made firstly between the two groups that would form the video or non-video groups and then between the video and non-video groups.

As some students left the groups between the time that the pre-test was taken and the first post-test administered these students were deleted from the original data and the tables in sections 7.2.2 and 7.2.3 do not include any data for such students. This removes the need to question the equivalence of the groups prior to the analysis of the first post-test due to students leaving the course.

Points	GCSE Grade	CSE Grade	GCE Grade
7	A	-	A
6	B	-	B
5	C	1	C
4	D	2	D
3	E	3	E
2	F	4	-
1	G	5	-

Table 27 - Points Assigned for GCSE / GCE / CSE Examination Results

Most of the data collected was presented without any modifications, but the students GCSE / GCE / CSE results were scored according to Table 27 and a mean total for each group given on the summary tables to be found in sections 7.2.2 and 7.2.3.

When the summaries of the background information had been prepared they were examined for any discrepancies between the constitution of the groups, with regard to the factors that had been identified in section 4.2 that were not able to be controlled by the design of the experiment. The results of the pre-test were then also considered, with a statistical analysis being carried out as described in section 7.1.

The number of students that were female, mature or taking physics were examined for the presence of any noticeable differences. The students' general academic ability was examined by testing statistically for any differences between the mean GCSE scores of the groups using a t-test and the procedure described in section 7.1. Their mathematical ability was also compared by examining the distribution of the mathematics GCSE grades in each group and testing for any differences between the video and non-video groups with a chi-squared test. It was not possible to use the procedure for testing described in section 7.1 because the cell counts were too small to permit a valid test to take place, so the video and non-video groups were compared directly.

When the pre-tests were marked, the students' scores were then considered and tested statistically using a t-test applied using the procedure of section 7.1. The results of the test being presented with the sizes, means and standard deviations of the two groups.

In the light of this background data and the results of the statistical tests decisions were then taken with regard to the equivalence of the groups. The following two sub-sections present the data for both years of the experiment and the conclusions reached.

As the experiment progressed investigation of the students performance on the tests suggested that comparisons of the students not taking A-level physics may be of interest. In order to make these comparisons the students not taking physics were treated as two groups one taught with and the other without video. Clearly if comparisons were to be made between these two groups they would have to be shown to be equivalent at the outset of the experiment, so sections 7.2.4 and 7.2.5 examine the background data and pre-test results for these students in years one and two respectively. The analysis of the results follows a similar approach to that for the complete set of data.

7.2.2 Results for Year One of the Experiment

The background questionnaire for the first year was completed by the participating students in October 1988. The results were collated as described in section 6.2.1 and are presented in Table 28.

	Video			Non-Video		
	A1	B1	Total	C1	D1	Total
Number in Group	16	10	26	15	14	29
Percentage Male	75%	50%	65%	73%	64%	69%
Percentage Female	25%	50%	35%	27%	36%	31%
Percentage Taking						
A Level Physics	44%	30%	38%	47%	57%	52%
Maths GCSE Grade A	13%	40%	23%	33%	36%	34%
Grade B	63%	30%	50%	40%	43%	41%
Grade C	25%	30%	27%	27%	21%	24%
Mean GCSE Results						
Score for Group	43.3	50.7	46.1	46.9	45.4	46.2

Table 28 - Summary of Background Information for Students in the First Year of the Experiment

An examination of Table 28 revealed that there were few differences between the four groups. The most noticeable were that group B1 had a greater

proportion of females and a lower proportion of physics students. However when the totals for the video and non-video groups were compared these differences were much less conspicuous, with only the smaller proportion of physics students being readily observable. When the mean GCSE results scores were tested using the procedure of section 7.1 there was no significant difference between the video and non-video groups. The results of this test are given in Table 29.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	26	46.1	6.1	0.04	53
Non-Video	29	46.2	10.4		

Table 29 - Comparison of GCSE Scores for Students in the First Year of the Experiment

The distribution of the mathematics GCSE grades was also compared with a chi-squared test. The test to compare the video and non-video groups yielded a chi-squared value of 0.73 with 2 degrees of freedom, indicating that there was no significant difference between the distribution of the students' GCSE grades for the two groups.

Thus the background questionnaire suggested that there were good grounds for assuming that the experimental and control groups were equivalent. Further evidence to support this assumption was found when the pre-tests were completed by the students in January 1989. The analysis of the results of the pre-test was carried out using the procedure of section 7.1, which indicated that there were no statistically significant differences between the groups that were combined to form the video or non-video groups and yielded the results that are given in Table 30, for the comparison of the video and non-video groups.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	26	24.3	6.5	1.41	53
Non-Video	29	27.1	7.6		

Table 30 - Results of the Pre-test for the First Year of the Experiment

Although the mean score for the video group was slightly lower than for the non-video group there was no statistically significant difference between the performance of the two groups on this test. This combined with the background information provided the evidence needed for the experiment to proceed based on the assumption that the control and video groups for year 1 were equivalent.

7.2.3 Results for Year Two of the Experiment

The background questionnaires for the second year of the experiment were completed by the students in October 1989 at the same time as they took the pre-test. The test being used at a much earlier date than for the previous year due to the changes to the teaching package outlined in section 4.5. The data obtained from the questionnaires was collated as described in section 7.2.1 and is presented in Table 31.

The examination of Table 31 revealed that there were few differences between the four groups, but that when they were combined these were even less evident. There were some differences in the ratio of males to females, with groups A2 and D2 having a greater proportion of males. However when the groups were combined the ratios became almost equal, the video group being 31% female and the non-video group being 28% female. Similarly the proportion of students taking A-level physics was higher in group D2. Again when the data was pooled the proportions were less different, with 47% of the video group and 56% of the non-video group taking physics.

	Video			Non-Video		
	A2	B2	Total	C2	D2	Total
Number in Group	16	16	32	10	15	25
Percentage Male	75%	63%	69%	60%	73%	68%
Percentage Female	25%	38%	31%	40%	27%	32%
Percentage Taking A Level Physics	50%	44%	47%	20%	80%	56%
Maths GCSE Grade A	19%	31%	25%	20%	47%	36%
Grade B	63%	50%	56%	50%	46%	44%
Grade C	19%	19%	19%	30%	13%	20%
Mean GCSE Results Score for Group	46.4	50.2	48.3	47.4	52.0	50.2

Table 31 - Summary of Background Information for Students in the Second Year of the Experiment

The mean scores obtained from the students GCSE/GCE/CSE results were compared using a t-test and the procedure of section 7.1. These tests showed no statistically significant differences between the two video groups or the two non-video groups. When the combined video and non-video groups were tested the results given in Table 32 were obtained.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	32	48.3	9.0	0.80	55
Non-Video	25	50.2	8.3		

Table 32 - Comparison of GCSE/GCE/CSE Scores for Students in the Second Year of the Experiment

These results clearly show that there is no statistically significant difference between the GCSE/CSE/GCE scores for the two different groups. A chi-squared test was also used to compare the distribution of the grades for GCSE mathematics. This yielded a value of 1.005 with 2 degrees of freedom, indicating

that there was no statistically significant difference between the distribution of the grades for the two groups.

The background information suggested that there were good grounds for assuming the equivalence of the two groups. The results of the pre-test provided further evidence to support this assumption. The pre-test results were analysed using the procedure of section 7.1. No statistically significant differences emerged when the two video groups were compared or when the non-video groups were compared. The groups were then pooled to give the results in Table 33.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	32	23.9	4.6	1.43	55
Non-Video	25	26.1	6.8		

Table 33 - Results of the Pre-test for the Second Year of the Experiment

The table shows that the mean score for the video group is slightly less than for the non-video group, but that this difference is not statistically significant. This information, in conjunction with that provided by the background data, provides the evidence needed to support the assumption that the two groups were equivalent and allows the experiment to proceed.

7.2.4 Results For The Students Not Taking Physics In Year One Of The Experiment

As the students not taking physics were of interest to the experiment and their results were also to be analysed, the equivalence of the video and non-video groups also had to be established at the outset of the experiment. The background information for the students not taking physics is summarised in

Table 34. These results have been collated in the same way as for the complete data, but only treated as two groups rather than four.

	Video	Non-Video
Number in Group	16	14
Percentage Male	44%	43%
Percentage Female	56%	57%
Maths GCSE Grade A	25%	29%
Grade B	50%	43%
Grade C	25%	29%
Mean GCSE Results Score for Group	46.6	44.7

Table 34 - Summary of the Background Information for the Students Not Taking Physics in Year One of the Experiment

An examination of Table 34 revealed that the two groups were very similar. When the mean GCSE scores were compared the results recorded in Table 35 were obtained, which indicated that there was no statistically significant difference between the performance of the two groups in this respect.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	16	46.6	6.6	0.54	28
Non-Video	14	44.7	11.6		

Table 35 - Comparison of GCSE Results for Students Not Taking Physics in Year One of the Experiment

Thus the background information points to the equivalence of the two groups. Further evidence was again provided by the pre-test results summarised in Table 36, which shows that the mean scores were very similar and that there is no statistically significant difference between them. Thus there was sufficient evidence to allow the two groups to be considered as equivalent.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	16	23.6	6.2	0.20	28
Non-Video	14	24.1	6.8		

Table 36 - Comparison of Pre-test Scores for Students Not Taking Physics in Year One of the Experiment

7.2.5 Results For The Students Not Taking Physics In Year Two Of The Experiment

An examination of the data for year two took place in the same way as for year one to establish the equivalence of the two groups of students not taking physics. Table 37 gives a summary of the background information that was obtained from the questionnaires.

	Video	Non-Video
Number in Group	17	11
Percentage Male	47%	45%
Percentage Female	53%	55%
Maths GCSE Grade A	41%	36%
Grade B	41%	36%
Grade C	18%	27%
Mean GCSE Results Score for Group	51.8	48.5

Table 37 - Summary of the Background Information for the Students Not Taking Physics in Year Two of the Experiment

Although the non-video group was smaller than the video group, the proportion of students in each category was similar. The most noticeable difference was that the mean GCSE score was lower for the non-video group. Table 38 gives the details of the comparison of the two groups GCSE scores, indicating that the difference is not statistically significant.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	17	51.8	5.9	1.02	26
Non-Video	11	48.5	10.7		

Table 38 - Comparison of GCSE Results for Students Not Taking Physics in Year One of the Experiment

The background information therefore points again to the equivalence of the two groups. This is confirmed by the results of the pre-test, summarised in Table 39. The non-video group mean was slightly greater than the video group, but the difference was not statistically significant. Thus it was possible to proceed with this aspect of the analysis of results as there was strong evidence to support the equivalence of the two groups being compared.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	17	22.1	4.5	0.93	26
Non-Video	11	24.0	5.9		

Table 39 - Comparison of Pre-test Scores for Students Not Taking Physics in Year One of the Experiment

7.3 Results For The Force Questions

7.3.1 Results For The First Year of The Experiment

The first post-test was administered in April 1989 after the students had completed the first block of the teaching package. The test contained only the original set of questions on force.

Of the students taking the test there was only one who had missed more than one video and so this student's result was omitted from the analysis. As this was a

very low level of alteration to the groups examined in section 7.2 no further re-examination of the pre-test results or background information was considered necessary. So it was assumed that the groups that are compared here were equivalent at the outset of the experiment. The results for the video and non-video groups taking this test were compared using a t-test following the procedure of section 7.1. No statistically significant differences were found between the two video groups or the two non-video groups so the results were pooled and the analysis continued. The results obtained for this test are summarised in Table 40.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	25	29.4	10.0	1.37	52
Non-Video	29	33.4	10.9		

Table 40 - Results for the Force Questions for Year One

Here the mean of the video group was lower than that of the non-video group but the t-value obtained indicated that this difference was not statistically significant. Thus it was concluded that there was no difference between the performance of the experimental and control groups for the force questions.

7.3.2 Results For The Second Year of The Experiment

In the second year of the experiment the force questions formed part of the first post-test along with the motion questions. This test was administered in February 1990, shortly after the teaching on force was completed.

Of the students in the video group there were two who did not take the test due to a period of absence, but all of the students who took the test had seen all four videos. Thus the loss of students from the video group was small, only 6% of the

original number. All the students in the non-video group had completed the teaching and took the test. Thus the loss of students from the experiment was very small and considered negligible at this stage, so no allowance was made for this in the analysis.

The results for the four groups were analysed using the procedure described in section 7.1, with no statistically significant differences emerging so that the results could be pooled. The results for the pooled groups are summarised in Table 41.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	30	24.0	7.4	1.28	53
Non-Video	25	26.5	6.8		

Table 41 - Results for the Force Questions for Year Two

The mean for the video group was less than for the non-video group, but the difference was not statistically significant. Thus it was concluded that there was no difference between the performance of the two groups of students on the force questions.

7.3.3 Results For The students Not Taking Physics In The First Year Of The Experiment

Of the students not following physics courses only one failed to watch all the videos. As this was so low the equivalence of the groups that was established in section 7.2.4 was assumed to hold without further investigation, with the score for this one student removed from the data.

When the test scores for the video students not taking A level physics were compared with the non-video students not taking A level physics the results in Table 42 were obtained.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	15	28.1	9.7	0.50	27
Non-Video	14	26.7	9.7		

Table 42 - Results for the Force Questions for Year One Students Not Taking Physics

It is interesting to note that the mean score for the video group is now greater than that of the non-video group, a reversal of the result for the complete groups. However the t-value indicates that this difference is not statistically significant. So it was concluded that there was no difference between the performance of the two groups.

7.3.4 Results for the students Not Taking Physics in the Second Year of the Experiment

All of the non-physics students involved in the year two video group of the experiment saw all the videos on the topic of force. One student in the video group failed to take the test due to absence and all the non-video students took the test. Thus the loss of students from the experiment was very small, only 6% of the original non-physics video group. As this loss was small the equivalence of the groups that was established in section 7.2.5 was not questioned and assumed to hold.

The test scores for the non-physics students were compared and the results summarised in Table 43.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	16	22.2	5.9	0.00	25
Non-Video	11	22.2	4.7		

Table 43 - Results for the Force Questions for Year Two Students Not Taking Physics

The means for the two groups were in this case identical, yielding a t-value of zero, clearly suggesting that there were no statistically significant differences between the performance of these two groups on the force questions.

7.3.5 Discussion of the Results for the Force Questions

As the results of the force questions have shown no significant difference between the performance of the video and non-video groups, either for the experiment as a whole or for the non-physics groups, it must be concluded that the videos used for teaching this topic have made no difference to the students' understanding of the concepts involved.

The question that must now be addressed is why the video has failed to make the impact that had been anticipated. The reactions of students to the video used as part of the experiment and in other situations have been discussed fully in chapter 6, but it is interesting to look briefly at some of the reactions to the videos used for the force topics. Table 44 summaries the students' rating of their interest in the four videos used.

Video	Very Interesting	Interesting	Boring	Very Boring
Newton's First Law	2%	55%	38%	5%
What is a Force ?	4%	22%	65%	9%
$F=ma$: Newton's Second Law	0%	20%	60%	21%
Action and Reaction	0%	37%	59%	4%

Table 44 - Student Ratings of Interest for the Force Videos

The figures given in Table 44 point to a possible explanation for the disappointing performance of the videos in this case. For all but the first of the videos shown the majority of the students failed to find the videos interesting. The reasons for this were discussed in chapter 6 and various conclusions reached from the students other responses on the questionnaire. However the fact that the majority of the video failed to interest the students, is probably one of the most significant reasons for its failure to improve the students understanding. Other factors such as the age and style of the video have probably all played a part in not providing improved student understanding.

7.4 Results for the Motion Questions

7.4.1 Results for Year Two of the Experiment

These questions were only used in the second year of the experiment and appeared on the first post-test some time after the video had been used.

All the students in the non-video group completed the required work and took the test. However there were two students in the video group who did not watch the video and one who failed to take the test. These losses accounted for only 9% of the original video group and so the equivalence of the groups was not questioned. When the scores of the groups were compared using the procedure

of section 7.1 no statistically significant differences were detected between the two video groups or between the two non video groups. The groups were then pooled to form a video group and a non-video group and the analysis continued. The results of this analysis are given in Table 45.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	29	4.0	1.6	2.14	52
Non-Video	25	5.1	2.1		

Table 45 - Results of the Motion Questions for Year Two of the Experiment

The difference between the means of these two groups was statistically significant at the 5% level, indicating that there was a difference between the performance of experimental and control groups on these questions, with the non-video students having the higher mean score.

7.4.2 Results for the Students not Taking Physics in the Second year of the Experiment

Two of the students in the video group failed to see the motion video reducing the size of the video group by 2 to 15. This was in fact a 12% reduction in the size of this group and so it was considered necessary to re-establish the equivalence of the two groups. Table 46 gives a revised summary of the background information for the non-physics students.

	Video	Non-Video
Number in Group	15	11
Percentage Male	47%	45%
Percentage Female	53%	55%
Maths GCSE Grade A	40%	36%
Grade B	40%	36%
Grade C	20%	27%
Mean GCSE Results Score for Group	52.7	48.5

Table 46 - Summary of the Background Information for the Students not Taking Physics in Year Two of the Experiment

The constitution of the two groups was still very comparable, both with approximately equal numbers of males and females and a similar distribution of mathematics grades at GCSE. There was a difference between the mean GCSE scores for the two groups, but testing revealed that this was not statistically significant at the 5% level. When the pre-test results for the two groups were compared there were no statistically significant differences between the scores of the two groups. So although some students had not seen the video and their test scores deleted from the data there was evidence that the two groups to be compared were still equivalent, allowing the comparison of the scores on the motion post-test questions to proceed.

The results for the non-physics students on the motion post-test questions are summarised in Table 47. This indicates that the performance of the non-video group was better than that of the video group, but that the difference observed was not statistically significant.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	15	3.7	1.6	0.84	24
Non-Video	11	4.3	2.0		

Table 47- Results for the Motion Questions for Year Two Students Not Taking Physics

7.4.3 Discussion of Results for the Motion Questions

Here the situation has arisen where the performance of the non-video groups had been significantly better than for the video groups. This video had been produced using guide-lines established at an early stage of the research as some video evaluation questionnaires had been completed, causing concern about its failure to produce the anticipated improvement in student understanding. An examination of the students reactions to this video on their evaluation questionnaires suggests a possible reason for this.

Although the guide-lines for the style and approach of the video had been developed as part of the research the actual content of the video had been stipulated by SMP. Thus during the production the research model was applied to content specified at a particular level. Of the students that have seen the video 42% had stated that they had found it either boring or very boring. Also many students felt that they had learned very little or nothing from the video. The main area of complaint by the students was the low level of the material covered by the video.

It seems possible that many students watching the video lost concentration, thinking that it was all too easy and that it had nothing to teach them. This reaction was probably more true in the case of the physics students who would almost certainly have undertaken similar graph drawing work at GCSE level.

Thus the video may have been at too low a level to help the majority of students and particularly those with physics backgrounds. This could well account for its failure to improve the understanding of students in this area.

7.5 Results for the Momentum Questions

7.5.1 Results for Year One of the Experiment

In year one of the experiment the momentum questions were administered along with the projectiles questions in June 1989. The extent of problems caused by students leaving the course or missing the videos, were considered before any analysis of results. Table 48 summarises the loss of students from the experiment for these reasons.

Group	A1(Video)	B1(Video)	C1(Non-Video)	D1(Non-Video)
Left Course	0	3	0	0
Missed Video/ Teaching	3	1	0	0

Table 48 - The Number of Students Lost From the Experiment for the Momentum Questions in Year One

The number of students leaving the groups involved was small, totalling three, but notably they were all from group B (one of the video groups). Thus as the size of the video group was reduced by 27%, it was considered necessary to establish that the remaining students would have been equivalent at the beginning of the course.

The procedure used was an exact repetition of that described in section 7.2 for the analysis of the background information and pre-test scores. Table 49 gives a revised summary of the background information for those students who took the

momentum test and had seen the video. There were no alterations to the details for the non-video students as no students had left these groups and all had carried out the required work on momentum.

	Video			Non-Video		
	A1	B1	Total	C1	D1	Total
Number in Group	12	7	19	15	14	29
Percentage Male	67%	43%	58%	73%	64%	69%
Percentage Female	33%	57%	42%	27%	36%	31%
Percentage Taking A Level Physics	42%	14%	32%	47%	57%	52%
Maths GCSE Grade A	17%	43%	26%	33%	36%	34%
Grade B	58%	43%	53%	40%	43%	41%
Grade C	25%	14%	21%	27%	21%	24%
Mean GCSE Results Score for Group	45.2	50.3	47.1	46.9	45.4	46.2

Table 49 - Revised Summary of the Background Information for the Momentum Test Questions

A study of this data revealed that there were a lot less students in group B1 who were studying physics and that this group also contained a higher proportion of females than the other groups. When the groups were combined to form the video and non-video groups these differences were less obvious but still apparent, with 32% of the video group taking physics compared with 52% of the non-video group. The proportion of females was similar with 42% of the video group being female compared with 31% of the non-video group.

When the results were analysed in line with the approach of section 7.2.1, the statistical tests indicated that there were no statistically significant differences between the combined video and non-video groups. However there was a statistically significant difference between the GCSE scores of the groups A1 and B1. Also it was impossible to undertake a chi-squared test for the maths grades because of the smaller cell counts.

Thus there was not such strong evidence, to support the assumption of equivalent groups, as there was for the original groups. However the fact that the pre-test scores and GCSE scores for the combined groups were not significantly different was considered sufficient in this case. It was based on these assumptions that the analysis was continued.

The results for the students' scores on the momentum test questions are summarised in Table 50. The mean scores for the two groups can be seen to be almost identical and the t-value confirmed that there was no statistically significant difference between the two groups.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	19	10.6	2.1	0.11	46
Non-Video	29	10.5	3.7		

Table 50 - Results for the Momentum Questions in Year One

7.5.2 Results for Year Two of the Experiment

In year two of the experiment the momentum questions were administered alongside the circular motion questions in December 1990. The results of these tests were affected substantially by a problem that arose in September 1990, as a result of the reorganisation of the teaching groups at Exeter College. The two video groups suffered some changes, but the non-video groups were drastically changed, with one being lost altogether. The extent of these problems is revealed by the data given in Table 51.

Group	A2(Video)	B2(Video)	C2(Non-Video)	D2(Non-Video)
Left Course	6	5	10	11
Missed Video/ Teaching	4	0	0	0

Table 51- The Number of Students Lost From the Experiment for the Momentum Questions in Year Two

	Video			Non-Video		
	A2	B2	Total	C2	D2	Total
Number in Group	6	10	16	0	4	4
Percentage Male	83%	60%	69%	0%	75%	75%
Percentage Female	17%	40%	31%	0%	25%	25%
Percentage Taking A Level Physics	67%	30%	50%	0%	75%	75%
Maths GCSE Grade A	17%	40%	31%	0%	75%	75%
Grade B	67%	40%	50%	0%	25%	25%
Grade C	17%	20%	19%	0%	0%	0%
Mean GCSE Results Score for Group	48.2	51.7	50.4	-	56.3	56.3

Table 52 - Revised Summary of the Background Information for the Momentum Test Questions

These losses in fact left a total of 16 students in the two video groups and only 4 students in the non-video groups. The small size of the groups suggested that comparisons between the performance of the two groups should be made with caution. A comparison of the two groups also revealed that there were now several differences in the constitution of the two groups. Table 52 shows the revised background information for the groups. For the non-video there was a greater proportion of the students studying physics. Also the non-video students had higher grades in both their GCSE mathematics and overall, although the difference for the overall scores was not statistically significant. When the pre-test scores were compared there was no significant difference between the two groups. So although there were some differences between the two groups, there was not sufficient to breakdown completely the assumption of equivalence.

The results for the students scores on the momentum test questions are summarised in Table 53. The mean score for the non-video group was slightly higher than for the video group, but the differences were not statistically significant.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	16	11.3	3.4	0.80	18
Non-Video	4	12.8	1.9		

Table 53- Results for the Momentum Questions in Year Two

7.5.3 Results for the Students Not Taking Physics in Year One of the Experiment

A number of the students who had left the course or not seen the momentum video were not actually studying physics and so the equivalence of the video and non-video groups could have been affected. Table 54 sets out the details of the loss of students, which corresponds to a 19% reduction in the size of the video group.

The effect of this loss on the constitution of the experimental and control groups was considerably less significant than for the complete groups. Again there were no changes to the non-video control group. The background information for the revised groups is given in Table 55.

Group	A1(Video)	B1(Video)	C1(Non-Video)	D1(Non-Video)
Left Course	0	2	0	0
Missed Video/ Teaching	1	0	0	0

Table 54 - The Number of Students Not Taking Physics Lost From the Experiment for the Momentum Questions in Year One

	Video	Non-Video
Number in Group	13	14
Percentage Male	38%	43%
Percentage Female	62%	57%
Maths GCSE Grade A	23%	29%
Grade B	46%	43%
Grade C	31%	29%
Mean GCSE Results Score for Group	47.3	44.7

Table 55- Revised Summary of the Background Information for the Students Not Taking Physics in Year One of the Experiment

Here there is clearly a strong similarity in the composition of the two groups. Further evidence to support their initial equivalence is given by the comparison of their GCSE and pre-test scores, neither of which differed significantly. Thus in the light of these conclusion a comparison was made of the performance of the students not taking physics on the momentum questions. The results of this comparison are given in Table 56.

These results showed that the mean score for the video group was higher than for the non-video group, with a difference that the t-value indicated to be statistically significant at the 5% level. Hence we can conclude that those students not studying physics who had seen the video performed better than those who had not.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	13	11.2	1.2	2.59	25
Non-Video	14	8.5	3.7		

Table 56 - Results for the Momentum Questions in Year One for the Students Not Taking Physics

7.5.4 Results for the Students Not Taking Physics in Year Two of the Experiment

As has already been described there were substantial losses from the groups of students involved in the experiment during the second year. This was particularly evident among the students not taking physics. When the momentum questions were administered there were 10 students in the video group, but only one in the non-video group. For this reason it was inappropriate to undertake any analysis involving the comparison of the results for the two groups. Table 57 summarises the results for the video group on the momentum questions.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	9	9.3	4.7	-	-
Non-Video	-	-	-		

Table 57 - Results for the Non-Physics Video Students on the Momentum Questions

7.5.5 Discussion of Results for the Momentum Questions

Although there was no significant difference between the results for the whole groups in either year one or year two there was a statistically significant difference between the two non-physics groups in year one of the experiment. It

was disappointing that there was not an opportunity to repeat this comparison in year two. So the video "Introduction to Momentum" has helped to improve the understanding of the students not taking physics.

Examining the students responses to the evaluation questionnaire discussed in section 6.2.5 indicates reasons why the video was successful with the non-physics students, but less so with the physics students. This video had appealed to the students with the majority finding it very interesting, they also had found that it was easy to understand and well explained. These factors would certainly account for the improved understanding that the non-physics students experienced, but not the difference between the performance of the non-physics and physics students. Another criticism that was made of the video referred to its low level and in addition a fair proportion of the students felt that they had learned little or nothing from the video. It would seem that these comments probably originate from students taking A-level physics who would have almost certainly met the concept of momentum in physics before. This video would be able to provide very few new insights into the concept of momentum for these students and so it would be unlikely that the video would promote improved understanding for the students who were taking A-level physics.

In conclusion the results of the experiment suggest that this video may have the potential to improve significantly the understanding of students who are not following A-level courses in physics.

7.6 Results for the Projectiles Questions on Post-Test Two

7.6.1 Results for Year One of the Experiment

In year one of the experiment the projectiles questions were administered along with the momentum questions in May 1989. The extent of problems caused by students leaving the course or missing the videos, which are summarised in Table 58, were considered before any analysis of results.

Group	A1(Video)	B1(Video)	C1(Non-Video)	D1(Non-Video)
Left Course	0	3	0	0
Missed Video/ Teaching	3	4	0	0

Table 58 - The Number of Students Lost From the Experiment for the Projectiles Questions in Year One

The number of students leaving the groups involved was small, totalling three, but notably they were all from group B (one of the video groups).

To have maintained an adequate level of viewing it was decided that the students must have seen both of the video modules if their results were to be included in the analysis of the results of the experiment. It was important that both videos were seen as they dealt with the two different aspects of projectile motion that were included in the test questions, the path and the range of a projectile.

The size of the video group was reduced by ten to sixteen. As this figure represented a substantial reduction in the size of the group by 38% it was considered necessary to establish that the remaining students were equivalent at the beginning of the course.

The procedure used was an exact repetition of that described in section 7.2 for the analysis of the background information and pre-test scores. Table 59 gives a summary of the background information for those students who took the momentum test and had seen the video. There were no alterations to the details for the non-video students as no students had left these groups and all had carried out the required work on projectiles.

	Video			Non-Video		
	A1	B1	Total	C1	D1	Total
Number in Group	9	7	6	15	14	29
Percentage Male	56%	43%	50%	73%	64%	69%
Percentage Female	44%	57%	50%	27%	36%	31%
Percentage Taking A Level Physics	33%	14%	25%	47%	57%	52%
Maths GCSE Grade A	22%	57%	38%	33%	36%	34%
Grade B	44%	29%	38%	40%	43%	41%
Grade C	33%	14%	25%	27%	21%	24%
Mean GCSE Results Score for Group	45.8	51.6	48.3	46.9	45.4	46.2

Table 59 - Revised Summary of the Background Information for the Projectiles Questions

An examination of this data revealed that there were considerably less students in group B1 who were studying physics and that this group also contained a higher proportion of females than the others. When the groups were combined to form the video and non-video groups these differences were less obvious, but still apparent. The proportion of physics students in the video group was 25% compared with 52% in the non-video group. The difference in the proportion of females was similar with 50% of the video group being female compared with 31% of the non-video group.

When the results were analysed in line with the approach of section 7.2.1, the statistical tests indicated that there were no statistically significant differences

between the combined video and non-video groups. However there was a statistically significant difference between the GCSE scores of the groups A1 and B1. Also it was impossible to undertake a chi-squared test for the maths grades because of the low cell counts.

Thus there was not such strong evidence, to support the assumption of equivalent groups, as there was for the original groups. However the fact that the differences between the pre-test scores and GCSE scores for the combined groups were not statistically significant was considered sufficient in this case. It was based on this assumption that the analysis was continued.

The results for the students' scores on the projectiles test questions are summarised in Table 60. The mean score for the non-video group is greater than that for the video group, but the t-value reveals that this difference is not statistically significant.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	16	7.4	2.8	1.46	43
Non-Video	29	9.1	4.0		

Table 60 - Results for the Projectiles Questions in Year One

7.6.2 Results for Year Two of the Experiment

In year two of the experiment the projectiles questions were administered on their own in June 1990. As was the case in the first year of the experiment there was some reduction of student numbers by the time that the projectiles tests were taken. These losses are recorded in Table 61.

Group	A2(Video)	B2(Video)	C2(Non-Video)	D2(Non-Video)
Left Course	0	1	0	0
Missed Video/ Teaching	0	2	2	3

Table 61 - The Number of Students Lost From the Experiment for the Projectiles Questions in Year Two

As Table 61 indicates 3 students had been lost from the video groups and 5 from the non-video groups. These correspond to reductions by 9% and 20% respectively, so it was decided that the initial data should be compared for the two groups containing the remaining students. Table 62 gives a summary of the revised background information.

	Video			Non-Video		
	A2	B2	Total	C2	D2	Total
Number in Group	16	13	23	8	12	20
Percentage Male	75%	62%	69%	63%	75%	70%
Percentage Female	25%	39%	31%	38%	25%	30%
Percentage Taking A Level Physics	50%	39%	45%	25%	92%	65%
Maths GCSE Grade A	19%	39%	28%	13%	50%	35%
Grade B	63%	39%	52%	63%	33%	45%
Grade C	19%	23%	21%	25%	17%	20%
Mean GCSE Results Score for Group	46.4	52.2	49.0	47.1	52.8	50.2

Table 62 - Revised Summary of the Background Information for the Projectiles Test Questions

The main differences that could be observed in this table were the small number of students taking physics in group C2 and the large number in group D2, however when the groups were combined these differences became less apparent. Otherwise the constitution of both groups appears to be very similar. When the GCSE scores and pre-test scores for the groups were compared using

statistical tests there were no statistically significant differences between either the individual or combined groups.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	29	10.7	3.9	0.52	47
Non-Video	20	11.3	4.0		

Table 63- Results for the Projectiles Questions in Year Two

Table 63 shows the results for the students that took the test containing the projectiles questions. The mean score for the non-video group is slightly higher than that of the video group, but the difference is not statistically significant.

7.6.3 Results for the Students Not Taking Physics in Year One of the Experiment

A number of the students who had left the course or had not seen both the projectiles videos were not actually studying physics and so the equivalence of the video and non-video groups could have been affected. Table 64 sets out the details of the loss of students, which correspond to a 31% reduction to the size of the video group. There were no changes to the non-video group.

Group	A1(Video)	B1(Video)	C1(Non-Video)	D1(Non-Video)
Left Course	0	2	0	0
Missed Video/ Teaching	1	2	0	0

Table 64 - The Number of Students Not Taking Physics Lost From the Experiment for the Projectiles Questions in Year One

As a result of these losses it was considered necessary to re-establish the equivalence of the experimental and control groups. The background information for the revised groups is given in Table 65.

	Video	Non-Video
Number in Group	11	14
Percentage Male	27%	43%
Percentage Female	73%	57%
Maths GCSE Grade A	36%	29%
Grade B	36%	43%
Grade C	27%	29%
Mean GCSE Results Score for Group	49.1	44.7

Table 65 - Revised Summary of the Background Information for the Students Not Taking Physics in Year One of the Experiment

Here there is clearly a strong similarity in the composition of the two groups, the only major discrepancy being with the difference in the proportion of male to female students. Further evidence to support their initial equivalence is given by the comparison of their GCSE and pre-test scores, neither of which differed significantly. Thus in the light of these conclusions a comparison was made of the performance of the students not taking physics on the projectiles questions. The results of this comparison are given in Table 66.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	11	7.1	3.0	0.73	23
Non-Video	14	8.1	3.5		

Table 66 - Results for the Projectiles Questions in Year One for the Students Not Taking Physics

These results showed that the mean score for the video group was less than for the non-video group, with a difference that the t-value indicated was not

statistically significant. Hence we can conclude that those students not studying physics who had seen the video performed no better than those who had not.

7.6.4 Results for the Students Not Taking Physics in Year Two of the Experiment

There were a number of students who were lost from the experiment at this stage. Table 67 indicates the losses among those students not studying physics at A-level. The loss from the video group is relatively small, only 6% of the original sample, but the loss from the non-video group is much greater being 36% of the original sample.

Group	A1(Video)	B1(Video)	C1(Non-Video)	D1(Non-Video)
Left Course	0	1	2	2
Missed Video/ Teaching	0	0	0	0

Table 67 - The Number of Students Not Taking Physics Lost From the Experiment for the Projectiles Questions in Year Two

As the losses were quite big it was necessary to re-establish the equivalence of the two groups before commencing the analysis of results. Table 68 shows the revised background information for the two groups.

	Video	Non-Video
Number in Group	16	7
Percentage Male	44%	43%
Percentage Female	56%	57%
Maths GCSE Grade A	44%	29%
Grade B	38%	43%
Grade C	19%	29%
Mean GCSE Results Score for Group	52.6	49.7

Table 68 - Revised Summary of the Background Information for the Students Not Taking Physics in Year Two of the Experiment

An examination of this revised data showed up only minor differences between the constitution of the two groups, other than the fact that the non-video group was very much smaller than the video group. Comparisons of these students' GCSE and pre-test scores using statistical tests showed that there were no statistically significant differences in these respects. Thus there was sufficient evidence to conclude that the two groups could be regarded as equivalent and allow the analysis to proceed.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	16	8.3	2.2	0.15	21
Non-Video	7	7.9	3.2		

Table 69 - Results for the Projectiles Questions in Year Two for the Students Not Taking Physics

Table 69 contains the results of the students for the projectiles questions. Although the mean score for the video students is slightly higher than for the non-video students, this difference is not statistically significant.

7.6.5 Discussion of the Results for the Projectiles Questions

In both years of the experiment there were no significant differences between the performances of the students using video and those not using video. Although the video has not led to improved student understanding it has not either resulted in a poorer level of understanding. So, although the video communicated with the students as well as a traditional approach, the issue that must be addressed is to attempt to identify why the video has failed to promote improved understanding. An examination of the responses to the video evaluation questionnaires described in sections 6.2.6 and 6.2.7 makes one suggestion.

The evaluation questionnaires had suggested that the level of student interest in the two videos was either reasonable or moderate and that the students had felt that they had learned something from the videos. However the appearance of the presenters on the videos was mentioned by a good number of students and is likely to have been a cause of some distraction. Also the video "The Optimum Angle" contained a certain amount of algebraic manipulation that the students disliked. It could well be that these two factors were significant enough to prevent students gaining an improved understanding from watching these two videos.

It was interesting to note that for the non-physics students the video group did perform better than the non-video group in year two and in year one the difference between the mean scores was less for the non-physics students than for the whole group. Although there are no statistically significant differences it may be that the videos do help those students who are not studying physics more than those who are studying physics.

7.7 Results for the Circular Motion Questions

7.7.1 Results for Year One of the Experiment

In year one of the experiment the circular motion questions were administered in January 1990, during the students' second year of study. There had been a number of changes to the groups as a result of the students performance in their end of first year examinations and also due to the rationalisation of the teaching groups. These factors caused the problems due to the loss of students to be exaggerated, particularly as group B1 (one of the video groups) was disbanded and its students re-allocated to other teaching groups. Table 70 provides details of the loss of students at this stage of the experiment.

Group	A1(Video)	B1(Video)	C1(Non-Video)	D1(Non-Video)
Left Course	5	10	4	5
Missed Video/ Teaching	3	0	0	0

Table 70- The Number of Students Lost From the Experiment for the Circular Motion Questions in Year One

The number of students leaving the groups involved was substantial, but of particular concern was the loss of the video group B1.

To have maintained an adequate level of viewing it was decided that the students must have seen both of the video modules if their results were to be included in the analysis of the experiments results. It was important that both videos were seen as they dealt with circular motion in two different situations, the first in a horizontal plane and the second in a vertical plane. The number of students who failed to maintain an adequate level of viewing was relatively small compared to the loss of students from the course.

As the size of the video group was reduced by 69% it was essential to reconsider the assumption that the experimental and control groups containing the remaining students were equivalent, at the outset of the experiment.

The procedure used was an exact repetition of that described in section 7.2 for the analysis of the background information and pre-test scores. Table 71 gives a summary of the background information for those students who took the circular motion test and had seen the video. There were also alterations to the details for the non-video students as some students had left these groups, but all the remaining students had carried out the required work.

	Video			Non-Video		
	A1	B1	Total	C1	D1	Total
Number in Group	8	0	8	10	10	20
Percentage Male	75%	0%	75%	90%	70%	80%
Percentage Female	25%	0%	25%	10%	30%	20%
Percentage Taking A Level Physics	50%	0%	50%	80%	40%	60%
Maths GCSE Grade A	13%	0%	13%	30%	50%	40%
Grade B	63%	0%	63%	50%	40%	45%
Grade C	25%	0%	25%	20%	10%	15%
Mean GCSE Results Score for Group	46.4	-	46.4	45.7	50.9	48.3

Table 71 - Revised Summary of the Background Information for the Circular Motion Test Questions for Year One of the Experiment

An examination of this data clearly indicated that there were few differences between the video group and the combined non-video groups. The proportion of both physics students and the male to female ratio were both very similar for the two groups. The only major difference was in the distribution of mathematics GCSE grades where the video group had a much smaller proportion of higher grades than the combined non-video groups. The distribution of these grades

could not be tested using a chi-squared test, because the cell counts were too small.

The GCSE results scores were tested and no statistically significant differences emerged between the two non-video groups or between the video group and the combined non-video groups. No statistically significant differences emerged either when the pre-test scores for these groups were compared in the same way.

Thus there was strong evidence that the students remaining in the experiment could be regarded as coming from two equivalent groups, although the size of the experimental group was very much smaller than the control group. The analysis of the post-test scores was then considered having established that there was evidence for the equivalence of the two groups.

The results for the students' scores on the circular motion test questions are recorded in Table 72. The mean score for the video group was slightly greater than that for the non-video group, but the t-value revealed that this difference was not statistically significant.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	8	13.7	3.2	0.43	26
Non-Video	20	13.1	3.1		

Table 72 - Results for the Circular Motion Questions in Year One

7.7.2 Results for Year Two of the Experiment

In year two of the experiment the circular motion questions were administered alongside the momentum questions in December 1990. The questions were not

used in their entirety as there had been a syllabus change at Exeter College, that had removed circular motion in a vertical plane.

There was also a considerable loss of students from the experiment, due to changes made at Exeter College as the students entered their second year of study. It transpired that the students who answered the circular motion questions having participated in the relevant teaching were exactly the same as those who had been considered in the analysis of the momentum questions for year two of the experiment. Clearly as the groups had changed considerably there was a need to re-establish the equivalence of the two groups, but as these students are exactly the same ones as considered in section 7.5.2, the equivalence established there also holds here.

The results of the students' performance on the circular motion test questions are recorded in Table 73. Here the mean score for the non-video group is slightly greater than for the video group, but the t-value indicates that this difference is not statistically significant.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	16	8.2	2.0	0.28	18
Non-Video	4	8.5	1.2		

Table 73- Results for the Circular Motion Questions in Year Two

7.7.3 Results for the Students Not Taking Physics in Year One of the Experiment

As described above there was a very substantial reduction in size of the video group and this was also reflected in the number of students not taking physics in the video groups. There was also some loss of students from the non-video

groups who were not taking physics. The loss of students is summarised in Table 74.

Group	A1(Video)	B1(Video)	C1(Non-Video)	D1(Non-Video)
Left Course	7	3	3	2
Missed Video/ Teaching	0	2	0	0

Table 74- The Number of Students Not Taking Physics Lost From the Experiment for the Circular Motion Questions in Year One

The effect of this loss on the constitution of the experimental and control groups was considerable and in actual fact left a video group containing only 4 students and a non-video group with 8 students. Despite the small size of the groups the analysis was continued, with an examination of the initial equivalence of these groups as the first step. The background information for the revised groups is given in Table 75.

	Video	Non-Video
Number in Group	4	8
Percentage Male	50%	38%
Percentage Female	50%	63%
Maths GCSE Grade A	25%	25%
Grade B	50%	63%
Grade C	25%	13%
Mean GCSE Results Score for Group	45.8	46.6

Table 75 - Revised Summary of the Background Information for the Students Not Taking Physics in Year One of the Experiment

There were few differences in the constitution of the groups that could be identified from the background information, the distribution of the mathematics GCSE grades was similar for both groups, but there was a greater proportion of females in the non-video group. When the mean GCSE scores for the two groups

were compared, no statistically significant difference was present. Similarly for the pre-test scores, no significant difference was observable. Thus it was considered that the groups were initially equivalent and their scores for the Circular motion questions could be compared. The results for the circular motion questions are given in Table 76.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	4	12.9	3.3	0.62	10
Non-Video	8	11.5	3.4		

Table 76 - Results for the Circular Motion Questions in Year One for the Students Not Taking Physics

The mean score for the video students was greater than that for the non-video group, but the t-value indicates that this difference is not significant. Hence we can conclude that there is no difference in the performance of the video and non-video groups on this test.

7.7.4 Results for the Students Not Taking Physics in Year Two of the Experiment

In year two of the experiment only one student not studying A-level physics remained in the non-video group, so that it was impossible to make any comparisons of the performance of the two groups. Table 77 shows the results obtained for the video group.

Group	Size	Mean	Standard Deviation	T-Value	Degs of Freedom
Video	9	7.8	2.2	-	-
Non-Video	-	-	-	-	-

Table 77 - Results for the Circular Motion Questions in Year Two for the Students Not Taking Physics

7.7.5 Discussion of the Results for the Circular Motion Questions

There were no significant differences observed in any of the comparisons made between video and non-video students who had taken the circular motion questions. The performance of the complete groups were very similar, with very little difference between the means scores for the groups in either year. The results clearly suggest that this video has done little or nothing to improve student understanding, but has been in no way detrimental to it.

Examining the students' responses on the evaluation questionnaires for this video, discussed in section 6.2.8, points to several reasons why students have failed to gain an improved understanding from this video. The first thing to note is that the level of student interest was very low. Also the students stated that they had found the video difficult to understand and felt that the explanation was poor, with a considerable proportion feeling that they had learned little or nothing from the video. The main factors identified by the students for their bad reaction were concerned with the presenter, the poor explanations, the length of the video and the extensive use of algebra. The lack of improved student understanding seems to be largely attributable to the quality and content of the video.

It is interesting to note that there was a greater difference between the means of the non-physics video and non-video groups, in the favour of the video group. This difference was not significant, but its presence does suggest that this video may help students not taking A-level physics more than those who are taking A-level physics.

7.8 Conclusions From the Results of the Experiment

The results obtained in this experiment provide very little, if any evidence to support the speculation that the use of video can improve student understanding of mechanics, as described in section 4.1. However there is only very limited evidence, in these results, that the use of video can impair student understanding of mechanics. The likely reasons for the failure of each of the videos used in the experiment to improve student understanding have already been discussed in the appropriate sections, but there are two common problems that emerge frequently in this discussion. These are the students previous experiences and the quality of the video, not just in technical terms but also in an educational context.

The first of these problems or barriers to improved understanding is that some of the students may have already encountered the material as part of their A-level physics courses. In year one and year two of the experiment respectively 45% and 51% of the students involved at the outset were also following A-level physics courses, which would contain a substantial mechanics content. The effect of this on the results of the experiment would be twofold. Firstly the students may well find the videos uninteresting and boring if they have already encountered the ideas and they could well switch off or be distracted from the video, not giving it the opportunity to improve their understanding. Secondly if they had already received a good grounding in the topic elsewhere some of both the video and the non-video students could have, or felt they had, high levels of

understanding before they had viewed the videos. In particular this could account for the non-video students having higher scores than they would have had without the extra teaching in physics. It is interesting to note that there were several cases where the results were reversed or improved in favour of the video group when only the students not taking A-level physics were considered.

The second problem or barrier to improved student understanding was concerned with both the technical and educational quality of the videos used in the experiment. It is clear from the responses of the students to the video evaluation questionnaires described in section 6.2 that some of the videos were of poor technical quality or poor educational quality. In some cases poor sound or picture quality has detracted from the students learning, while in others bad presentation has hindered student learning. The aspects of bad presentation were factors such as the use of distracting presenters, not making the content relevant, using too much algebraic manipulation or not pitching the video at an appropriate level. The model formulated in section 6.3 deals with these factors in more detail. Several of the videos used fall into this category and while they do not hinder student understanding they achieve little that conventional teaching cannot.

The only statistically significant difference in student performance, in favour of the use of video, that emerged during the experiment was for the students not taking A-level physics on the momentum questions where the video group was significantly better than the non-video group. Here is a situation where the first barrier to improved understanding has been removed, as none of these students study physics, and there is little evidence of the presence of the second barrier. It is interesting to note that this was one of only two videos included in the experiment that had been designed specifically for sixth form mathematics students.

It is worth comparing these results with those of Hake (1987), who considered that the use of video had played a significant part in the improved student understanding that he had observed. It is unlikely that either of the two problems described above would apply to Hake's experiment. Britain is almost unique in including a study of mechanics in both the subject areas of physics and mathematics. As a physics teacher Hake would not have had the problem that the students involved in his experiment received other mechanics teaching. It also seems from his description of the videos used that they suffered from few of the problems that were encountered with the videos used here.

In conclusion there is no evidence to suggest that the use of video can impair student understanding, but if video is to improve student understanding it must satisfy the following conditions;

(i) it is of good technical and educational quality; (ii) it is used with students at an appropriate stage of their studies.

If these two conditions can be satisfied then there is a potential for the use of video to promote improved student understanding. The model formulated by this research and described in section 6.3 should, if implemented, lead to the availability of video resources that would satisfy condition (i). The second is more of a problem, especially in British schools and colleges, where mechanics is to be found in both mathematics and physics courses. There is a need for careful planning by teachers and a close liaison between departments.

Chapter 8 - A-Level Mathematics Students Intuitive Understanding of Mechanics Concepts

8.1 Introduction

This chapter describes the results of the trials of the pre-tests carried out with local sixth-forms and the results of the pre-tests for both years of the video experiment. In all this provided up to about 200 responses for most of the questions used. The actual number varies from question to question as they were not all used in the trials of the pre-test and some were only used on one of the pre-tests. However for most of the questions a good number of students drawn from a variety of institutions have attempted them.

This chapter provides a new look at understanding of mechanics because it has examined the understanding of mathematics students at or near to the beginning of their courses in mechanics. Almost all of the existing research has concentrated on physics students often at university or American college levels. The only exception to this being Roper (1985) who worked with A-level mathematics students, on a limited range of topics.

The students who had completed the trial tests or the pre-tests may have been introduced to the concepts of kinematics but had not experienced any formal teaching of force or the other concepts covered here. So this chapter does present very much a view of the students intuitive understanding of these concepts. This new viewpoint provides valuable information to the teachers of mechanics as it allows the identification of the state of student understanding that teachers can expect to find when commencing an A-level mathematics course. There may be conceptual ideas that teachers would expect students to have grasped before they

come to the mechanics classroom, but the findings described here indicate that this may not be true for all students.

This chapter sets out for the first time a comprehensive review of the problems that have been identified in the mathematics students involved in the trials and the experiment, giving an indication of the extent to which they affect the student population and the reasoning that is used by the affected students.

8.2 Kinematics

8.2.1 Velocity and Speed

It emerged from the students' responses that there was considerable confusion between the two concepts of velocity and speed. In many cases the way students used the two terms made it quite clear that they did not understand the difference between the two concepts, and felt free to interchange them. It became apparent from their responses that many of them had no idea of the vector nature of velocity, although they used the term freely. One such response from a student who clearly did not understand the full meaning of velocity was:

"The velocity is constant and in one direction".

This type of misunderstanding was a common feature of many on the students test papers, where the term velocity was used but not with the same meaning as a mathematician. Question 4 of the pre-test was designed to assess whether or not the students could distinguish between these two concepts.

4. A small ball is fired into the tube shown at high speed. The tube has very smooth sides and lies on a horizontal, smooth table. The diagram shows the tube viewed from above as it lies flat on the table. If the speed of the ball is constant describe what happens to the velocity of the ball while it is in the tube.



Figure 37 - The Diagram for Question 4

Responses	Percentage of Students
Direction of velocity changes, but not magnitude.	7%
Direction of velocity changes.	28%
Velocity changes	13%
Velocity increases / decreases	24%
Velocity remains constant.	16%
Other / no responses	13%
Sample size = 134	

Table 78 - Summary of Students Responses to Question 4

It can be seen from Table 78 that 35% of the students were aware that velocity has direction and that this was an important characteristic, although only a few of them referred to its magnitude. From their responses it seems reasonable to assume that these students had an understanding of the vector nature of velocity and were able to apply this to different situations.

The 16% of the students, who stated that the velocity of the ball remained constant, were clearly interpreting the velocity of an object to be its speed. They clearly had no conception of the vector nature of velocity and treated it purely as a scalar.

Between these two extreme responses there existed a group of students that had leanings towards either of the two view points set out above. Their statements referred to changes in velocity but did not mention its direction. Forming the bulk of this group were 24% of the students who had predicted that the velocity would increase or decrease. The way that they described the change implied that they thought of it as a scalar rather than a vector. The decrease is generally attributed to friction, but the increase is more difficult to explain. However some of the responses suggested that some of these students may have moved beyond simply treating velocity as if it were speed, but had not yet assimilated the real vector nature of velocity and so resorted to using increase or decrease to describe the change. The responses below illustrate this type of reasoning;

"It increases at a constant speed";

and

"The velocity decreases - because it is changing direction".

This confused type of response could come from students who need to grasp the concept of a vector to allow their understanding to progress, having differentiated between velocity and speed, but not attributed a complete meaning to velocity.

There was a further 13% of the sample who simply stated that the velocity changed. These could have been correctly thinking of the change in direction or an increase/decrease as just described. It was difficult to decide whether these students see velocity as a vector or as a scalar, especially as no justification was given for these responses.

In addition to the responses that have been described above, 11% gave other responses or none at all. Many of these in this category clearly did not see any

association between velocity and speed. This is clearly illustrated by a response such as:

"The velocity of the ball is zero".

Other questions, which asked the students to compare the speeds of objects, were often answered in terms of distances covered rather than referring to the speeds. This suggests that some students may have been using a position criterion to judge speed, which is a phenomenon that Trowbridge and McDermott (1980) had observed in their research based on college students. Question 17 on the test had been included specifically to test for the presence of this approach.

17. A motorbike is overtaking a car on a motorway. How do the speeds of the two vehicles compare at the instant they are level?

The students responses to question 17 are summarised in Table 79.

Responses	Percentage of Students
Motorbike has greater speed	66%
Motorbike and car have equal speeds	24%
Other / no response	9%
Sample size = 201	

Table 79 - Summary of Students Responses to Question 17

A significant 24% of the students stated that the two vehicles had equal speeds at this position. These students were using a position criterion to compare the speeds. That this approach is being taken is evident from responses such as:

"They are the same at that point".

Some of these responses used remarks about the acceleration of the car and motorbike to justify their responses, such as:

"Their speed is equal (their acceleration is different)".

From these results it could be concluded that while some students understand the vector nature of velocity, others see velocity and speed as equivalent and some do not even associate the two terms. Additionally some students used a position criterion to judge speeds.

8.2.2 Acceleration

As with velocity one noticeable deficiency in the student's understanding of acceleration was of its vector nature. They generally seemed to have a reasonable idea of the meaning of acceleration in the case of linear motion and often they attempted to apply this to two dimensional motion.

Question 7 on the test was designed to test student understanding in this area, by looking at circular motion.

7. As a motorcycle goes round a roundabout its speed remains constant. What happens to its acceleration?

Some of the responses to this are discussed more fully in the circular motion section, but it is interesting to examine the summary of responses given in Table 80.

Responses	Percentage of Students
Directed towards centre of the circle	15%
Acceleration changing	10%
Acceleration constant	16%
Acceleration zero	35%
Acceleration increasing or decreasing	18%
Other/no responses	6%
Sample size = 141	

Table 80 - Summary of Students Responses to Question 7

The most popular response from 35% of the sample was that the acceleration was zero. This clearly indicated that these students had no understanding of the vector nature of acceleration and interpreted acceleration solely as the rate of change of speed, which is zero as the speed is constant. The statements below illustrate typical examples of this reasoning:

"Nothing - it's speed is constant so there is no acceleration";

or

"There is no acceleration if the speed is constant".

Another response category that did not seem to show any understanding of the vector nature of acceleration was that the acceleration was constant, with 16% of the students giving this type of response. This category was discussed in the section on circular motion.

A frequently used response was that the acceleration was increasing or decreasing. Often these statements were unsupported and did not reveal a great deal about the students' reasoning. However, some responses revealed one line of thought, as illustrated by:

"It increases as velocity changes constantly. Acceleration is change in velocity over time".

Here the student had recognised that because the velocity was changing an acceleration must be present, and had described it as increasing because he did not have a full understanding of the concept. The definition of acceleration used by this student was in fact for average acceleration, again indicating that the student did not have a complete understanding of acceleration. It is unlikely that all the responses in this category were derived in the same way, but it was interesting to see some of the approaches that were taken.

An interesting comparison was made by looking at the responses to question 4 on the vector nature of velocity and this question on the vector nature of acceleration. It was found that 17% of the students gave responses to both questions that indicated that they had some understanding of how these quantities had direction as well as magnitude. Also 66% of the students did not refer to the direction on either of these questions. These comparisons suggested that a high proportion of the students were not aware that direction is needed as well as magnitude to describe these quantities.

Question 15 was also particularly revealing with regard to student understanding of acceleration. The responses to the first part of this question are recorded in Table 81.

15. A ball is thrown vertically, up in the air, as shown in the diagram. At A it is on its way up, at B it is at its highest point and at C it is on its way down. Draw arrows to show the direction of the acceleration at each of these three points?

How does the magnitude of the acceleration of the ball compare at each of these three points?

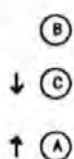


Figure 38 - The Diagram for Question 15

Response	Position		
	A	B	C
Up	45%	3%	5%
Zero	0%	60%	0%
Down	42%	27%	81%
Other / no response	13%	10%	12%
Sample size = 139			

Table 81 - Summary of Student Responses to Question 15

Some of the students did not draw arrows, but tried to describe the acceleration in words. They used a variety of approaches, some of which were correct, but generally did not seem to appreciate that a direction could be assigned to an acceleration, providing further evidence that these students do not consider acceleration to be a vector.

The responses to this question provided strong evidence that many students associate the direction of the acceleration with the direction of the motion. Further the responses to the second part of the question indicated that a

significant proportion of the students also associated the magnitude of the acceleration with the magnitude of the velocity. This part of the question asked the students how the magnitude of the acceleration compared at the three positions. Here 41% of the sample stated that it was zero at B and greater at A than at C. The reasoning here was obviously that the magnitude of the acceleration is linked to the speed of the object.

The responses made it clear that there were a considerable number of students who were confused about the difference between velocity and acceleration. This confusion was particularly noticeable if the magnitude of the velocity was zero. In addition this confusion could be observed in the language used by the students, as can be seen here when describing the acceleration of the ball:

"The ball is stationary at B, and faster at C than A".

Further evidence in support of this confusion appeared in the responses to the question described in the momentum section. One approach taken by the students was to use the expression $F = ma$, substituting the speed of the object as if it were the acceleration.

This confusion between velocity and acceleration was also identified by Trowbridge and McDermott (1981) in their study of undergraduate students' understanding of acceleration.

It is reasonable to conclude that many students have difficulty appreciating that acceleration is a vector quantity and also that they confuse the concepts of velocity and acceleration.

8.2.3 Kinematics and Graphs

One of the questions that looked at students ability to interpret graphs was part (b) of the first of the new pre-test questions.

14. The graph below shows distance against time graphs for two objects, A and B.

(b) Do A and B ever move at the same speed ?

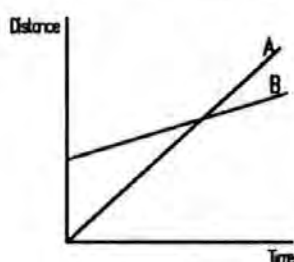


Figure 39 - The Diagram for Question 14

The students responses to this question are summarised in Table 82.

Response	Percentage of Students
No	58%
Yes	40%
Other / no response	2%
Sample size = 62	

Table 82 - Student Responses to Question 14(b)

The 40% of the students who stated that the two objects have the same speed at some time were assuming that when the two lines cross then the speeds are the same. Here the students are associating the speed with the height rather than the gradient of the graph. Similar strategies had been reported by McDermott et al. (1986) who had reported on the ability of college students to draw and interpret

graphs. There were also similarities between this and the overtaking motorbike of question 17. Here it could again be argued that the students were using a position criterion to compare speeds and it is possible that some students did this, but the higher proportion giving incorrect answers suggested that it was the interpretation of the graph that was the major obstacle to giving a correct response to this question.

The work of McDermott et al. (1986) also revealed that many students would attempt to draw distance-time graphs that looked like the path taken by the moving object. The third of the new pre-test questions had been included to test for this type of misinterpretation.

21. A car moves along the track shown below. From A to B its speed is increasing and from B to C its speed is decreasing, until at C is momentarily still before rolling back down the track. On the axes below sketch a distance-time graph for the car as it moves from A to C.

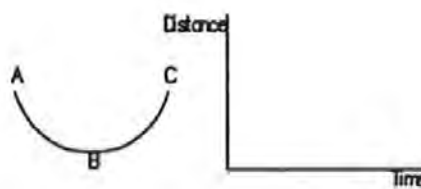


Figure 40 - The Diagram for Question 21

The students' responses to this question are summarised in Table 83.

Responses	Percentage of Students
Acceptable response	34%
Inverted "u" shaped graph	53%
Other/no responses	13%
Sample Size = 62	

Table 83 - Summary of student responses to Question 21

The majority of students drew a graph that was similar to that of the track but actually inverted. This could be that they were looking at the vertical displacement of the car from its starting point, but this seemed unlikely, particularly as the typical gradients did match with the speed of the car. The most likely explanation for this response was that the students felt constrained by the shape of the track but could accept that the displacement would decrease and then draw the incorrect path which suggested an increasing distance in the initial stages. The reasoning described above presents possible strategies taken by the students, but these cannot be regarded as exhaustive and there could well have been other approaches that lead to the same response. However it was clear that the students did not consider how the gradient of the curve should give the speed of the body. The incorrect response given by 53% of the students had a zero gradient at the point where the car actually reached its maximum speed.

In conclusion many students seem to have problems with the interpretation of distance-time graphs. These fall into two categories. Firstly the inability to represent a situation that has been observed or described on a graph. Secondly being unable to decide which features of a graph provide relevant information , for example whether to consider the height or the gradient.

8.3 Force and Newton's Laws

A number of the questions on the test were designed to ascertain whether the students would intuitively anticipate the consequences of applying a force to an object in a way that would be consistent with Newton's Laws. Particular areas of interest were understanding of Newton's first law and the relationship $F = ma$. A few questions also considered the third law. Much research has been carried out into student understanding of force, for example by Viennot (1979), but this has generally been with undergraduates and assumed that the concept of force has been met. The approach taken here was based at a much more intuitive level.

The first question on the paper was designed to investigate how students would expect an object to move when a force acts on it.

1. A spaceship is stationary deep in space. It fires its engines for two minutes and then turns them off. How does the speed of the rocket change during this two minute period?

What happens to the motion of the spaceship after this period, when the engines are turned off?

On the axes below sketch a graph of speed against time for the motion of the spaceship.

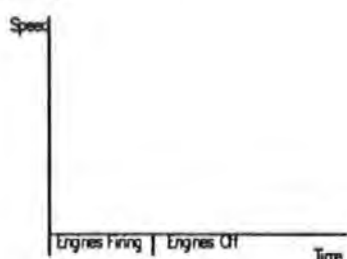


Figure 41 - The Diagram for Question 1

An identical spaceship that is carrying a heavy load fires its engines in exactly the same way. How does its motion compare with the original one?

Also sketch a graph of speed against time for this second spaceship on the same set of axes. Clearly label each graph that you draw.

The responses to this question are recorded in Table 84.

Responses	Percentage of Students
Speed increases	85%
Speed increases to maximum and remains constant	11%
Other / no response	4%
Sample size = 202	

Table 84 - Summary of Students' Responses to Part One of Question 1

The majority of the students gave correct responses, but the idea of a maximum speed for the rocket was a cause of concern. This small group of students seem to be unable to ignore the influence of the resistive forces that complicate motion on earth. Further evidence of this idea of a maximum speed appeared in the responses to another question where a similar proportion of the students answered in the same way.

The students encountered more difficulties with the second part of the question, which asked them to describe the motion of the spaceship when the motors were turned off. The responses to this part of the question are recorded in Table 85.

Responses	Percentage of Students
Moves with constant velocity	19%
Moves with constant speed	43%
Slows down	35%
Other / no response	3%
Sample size = 201	

Table 85 - Summary of Students' Responses to Part Two of Question 1

A good proportion predicted that the speed would remain constant, but only a much smaller number of the students also considered the direction of motion. This was perhaps because the students were not used to describing a motion in terms of its speed and direction, as they gave no indication that it should change.

The other response reveals a fundamentally incorrect approach, used by 35% of the sample. These students clearly regarded the force exerted by the motors as being necessary to maintain motion, as well as to start it. This approach was very similar to that described by Viennot (1979), where she sets out the alternative strategies used by students.

The final part of this question asked the students how the motion of an identical spaceship carrying a heavy load would compare with the original one. Their responses are recorded in Table 86 and refer to the first part of the motion while the engines are on.

Responses	Percentage of Students
Speed increases but at a slower rate	77%
Speed increases at an identical rate	12%
Speed increases at a lower rate initially, but reaches the same maximum speed	5%
Others / no responses	5%
Sample size = 201	

Table 86 - Summary of Students' Responses to the Final Part of Question 1

The responses for the second part of the motion were generally correct if the response for the original spaceship had been correct. Otherwise they were confused with no real trends evident from the students responses.

Although the majority gave correct responses, the other two categories are of interest. Of those that said that the motion would be the same, the main reasons given to support this response was the absence of gravity or the weightlessness of the spaceships. Thus these students argued that as the ships are weightless, they move as if they were identical, as illustrated by this brief response:

"Same (weightless in space)".

They did not appreciate that when away from the influences of gravity, an object still has a mass, and it is this that is important.

Some of those who said that the motion was identical, also indicated that the spaceships would reach a maximum speed before the rockets engines were switched off. This maximum speed argument was again present in the other incorrect response given by 5% of the students. They however predicted that the speed would increase more slowly taking longer for the spaceship to reach its maximum speed. These students seem committed to the idea that associated with every force there is a maximum speed, which is independent of the mass of the

object. However some of them did acknowledge that the speed of an object with a larger mass does increase more slowly.

Further questions where objects of different masses were acted on by identical forces, provided further evidence that most students had a good intuitive understanding of the role of mass in determining motion.

Most of the questions considered have only dealt with forces acting in the direction of motion. Question 23 involved a situation where a force was applied perpendicular to the direction of motion.

23. A football is rolling along the dotted line shown in the diagram. When it gets to the point X it is kicked by a boot that moves in the direction shown by the solid arrow. Draw the path of the ball after it has been kicked, if the diagram shows the motion of the ball viewed from above.



Figure 42 - The Diagram for Question 23

The responses that the students gave to this question are summarised in Table 87.

Responses	Percentage of Students
Is deflected from its original path	44%
Moves in the same direction as the force acts	34%
Other/no responses	22%
Sample size = 200	

Table 87- Summary of Student Responses to Question 23

While 44% gave the correct response, a very significant 34% predicted that the new path would be in the direction of the force. These students assumed that the ball will move in the direction of the force, taking no account of the existing motion of the ball.

Two questions examined student understanding of Newton's third law. The first of these was question 3.

3. You and a friend, who is the same size and mass as you, are standing still facing each other on roller skates. If you push your friend what happens

(a) to you?

(b) to your friend?

In describing the motion of the skater who gave the push, 90% of the students stated that he would move backwards, with the remainder giving various other responses. The responses for the motion of the skater who was pushed are recorded in Table 88.

Response	Percentage of Students
Goes backwards with the same speed/distance as the other skater.	36%
Goes backwards	43%
Goes backwards with a greater speed than the other skater	8%
Other / no response	12%
Sample size = 201	

Table 88 - Summary of Student Responses to Question 3(b)

It is encouraging that 36% of the sample gave correct predictions, showing a good intuitive understanding of the third law. The 8% that said that the skater who was pushed goes backwards at a greater speed than the skater who did the pushing, are probably intuitively aware that both should move but feel that the one that was pushed should go faster, because he actually did the pushing. Of the 43%, who stated that the skater would move backwards, it was likely that some would be sympathetic to either of the above arguments, but it seemed unlikely that they would have strong reasons for adopting either of these views.

A further question on Newton's third law was more complicated, as it involved other factors, and had objects of unequal masses. The majority of students again predicted that both objects would move, but very few made any mention of the momentum or speed of the two objects.

For situations where motion was confined to one dimension the majority of the students had reasonable intuitive ideas about the relationship between force, mass and motion, while the force is applied. However they did have significantly more difficulty when the force was removed or applied in two dimensions. Their understanding of the third law, although it lacked much recognition of the magnitudes of the forces, did indicate that the students did imagine two forces acting in opposite directions.

8.4 Momentum

One question, number 2, was included where the students needed to consider the product of mass and speed.

2. Which of the following is most likely to break a window?

A - A 500g ball moving at 2m/s

B - A 300g ball moving at 4m/s

C - A 100g ball moving at 9m/s

Why did you choose this one?

The responses to this question are recorded in Table 89.

Responses	Percentage of Students
300g at 4m/s	54%
100g at 9m/s	37%
500g at 2m/s	7%
Other / no response	2%
Sample size = 202	

Table 89 - Summary of Student Responses to Question 2

The majority of the students gave correct responses, but not all of these used valid arguments. However a good proportion did and these adopted one of three different approaches. The first of these was a good intuitive argument based on a compromise between the speed and the mass, such as:

"Because it would have been going at a reasonable speed, and was a reasonable weight to have broken the window".

The second approach, again of an intuitive nature, was to consider the inertia of the balls. This approach seemed to assume the same type of argument as illustrated above to estimate the inertia. Finally there were the students who calculated the product of mass and speed for each ball, selecting the one for which this was greatest. Some of these actually referred to the momentum of the ball being the important factor.

The rest of the students who gave the correct response used unacceptable reasoning to arrive at their conclusion. The prevalent approach was to justify it by applying Newton's second law, but taking the acceleration to be equal to the speed. A typical response of this nature was:

"force = ma (mass x acceleration) 4 x 300 gives the greatest value".

An examination of the other incorrect responses was also interesting. The most favoured approach was to select the ball with the greater speed, ignoring the mass. The proportion considering the mass rather than the speed was very much smaller. Interviews, that had been conducted with local sixth formers on the concept of momentum, also revealed that students who didn't consider the product felt that a greater speed implied a greater momentum.

8.5 Circular Motion

Two of the questions on the test paper concerned the path of an object that had been describing circular motion when the constraining force was removed. McCloskey et al. (1980) had identified deficiencies in student understanding of this area when working with undergraduate university students. Their results suggested that a significant proportion of the students would expect the circular

motion to continue, but spiralling out from its original path. The first of these was question 4.

4. A small ball is fired into the tube shown at high speed. The tube has very smooth sides and lies on a horizontal, smooth table. The diagram shows the tube viewed from above as it lies flat on the table. Draw the path of the ball after it leaves the tube.



Figure 43 - The Diagram for Question 4

The responses to this question are summarised in Table 90. From the table it can be seen that only a fairly small proportion of the students felt that the circular motion continued in the form of a spiral.

Responses	Percentage of Students
Path a tangent	73%
Curved path	15%
Straight path inside tangent	6%
Other / no response	5%
Sample size = 203	

Table 90 - Summary of Student Responses to Question 4

It is interesting that 6% drew a straight line, between the tangent and the centre of the circle, presumably because it has been influenced in some way by the original circular motion. Another similar question was number 11 on the test.

11. Figure 5 is drawn looking down on a ball on the end of a piece of string that is being swung round in a horizontal circle at fairly high speed. On the diagram draw the path of the ball if the string breaks at the point marked X.



Figure 44 - The Diagram for Question 11

The student responses to this question are summarised in Table 91.

Responses	Percentage of Students
Path a tangent	52%
Path that spirals out	16%
Straight path between tangent and centre	5%
Straight path outside tangent	24%
Other / no responses	2%
Sample size = 202	

Table 91 - Summary of Student Responses to Question 11

Here the proportion giving the correct response was significantly less, but the proportion envisaging continued curved path, in the form of a spiral, was about the same. Further examination of the test papers revealed that 6% of the sample drew a curved path on both questions. Almost all of those who drew a curved path for only one question, drew a tangent on the other. As well as the curved path a new type of error emerged on this question, the path that went outside the tangent. Students giving this response must have imagined that the ball would have been pulled outwards in some way. It is interesting that an 'outward' path

was only once drawn by a student who had previously drawn a curved or inward path.

Thus it seems that apart from the correct reasoning, used by 52% of the students on both questions, there existed two other almost exclusive approaches to the problem. Firstly the view that a curved motion continued or that the path was straight but had been pulled in towards the centre in some way. The second approach implied that the ball was thrown out in some way, suggesting that the students may have been thinking that some force throws the ball out.

The velocity and acceleration of objects describing circular paths have already been discussed in the sections on velocity and acceleration. However there were some points that were specifically relevant to circular motion. A number of the students had stated that the direction of the acceleration was changing, also explained that it would always be directed towards the centre of the circle. The 15% of the sample who gave this response obviously had an understanding of the acceleration of an object describing circular motion. A second group of students consisting of 16% of the sample stated that the acceleration was constant. They obviously did not understand the vector nature of acceleration, but their answer was not consistent with someone who regarded acceleration as the rate of change of speed. One plausible explanation was that they have encountered the expression v^2/r as part of their physics teaching and applied this without realising that it was directed towards the centre.

Finally question 22 considered the use of motion in a vertical circle, at constant speed.

22. A conker on the end of a piece of string is swung round in a vertical circle at a constant rate.

(a) At which point on the circle is the string most likely to break?

(b) If a shorter piece of string were used at the same rate of rotation, would it be more or less likely to break?

(c) If a longer piece of string were used, would it be more or less likely to break?

The students responses to question 22 are recorded in Table 92.

Responses	Percentage of Students
Lowest point	46%
Highest point	16%
Other points	33%
No responses	6%
Sample size = 199	

Table 92 - Summary of Student Responses to Question 22

The correct responses were generally unsupported, but when they were the statements were very vague, so that no patterns emerged from the students other responses. It seemed that this question was answered using purely the students intuition and that they have not encountered this type of problem before, unlike many of the others that are included in physics courses.

When considering circular motion it was clear that some students used ideas that they have been taught, but it was also evident that they used a lot of their own intuitive ideas. The difference in responses for the first two questions supported this as some of the students used different approaches to the same problem set in two different contexts. Ideas that the students had assimilated about circular motion from other teaching were not always used or applied correctly.

8.6 Gravity

Students' intuitive understanding of gravity was an area of some concern to Roper (1985), in one of the few studies that have looked at A-level students' understanding of mechanics. His research revealed that this was a particular problem for some students, and needed really to be examined in more detail. When preparing the test it seemed appropriate, in the light of the comments, to include questions that would examine student understanding of the concept of gravity. Question 9 in the test was concerned with gravity.

9. Two balls are exactly the same size and shape, but have masses of 1kg and 3kg. They are dropped at the same time from the same height. How does the time that they take to fall to the ground compare?

If this experiment were repeated on the moon, how would the results compare?

The responses to the first part of this question are recorded in Table 93 and to the second part in Table 94.

Responses	Percentage of Students
Balls land together	53%
3kg lands first	31%
3kg lands first in one third of the time	14%
Other / no responses	2%
Sample Size = 200	

Table 93 - Summary of Student Responses to Part One of Question 9

Although the majority of the students gave the correct response, a significant proportion thought that the balls would land at different times, the heavier one

first. This response was supported by one of three approaches. The first of these was an argument that assumed that the time taken for the 3kg ball to fall was one third of the time taken by the 1kg ball, as illustrated by this response:

"3:1 3kg ball gets there faster".

It appears that these students were assuming that the time taken to fall was inversely proportional to the mass, but whether the students would still use the same reasoning when considering balls of masses, say, 2kg and 3kg is uncertain. This type of response accounted for 14% of the total sample, although others could have used it but did not state as explicitly how the times compared.

Many of the remaining responses simply stated that the 3kg ball would land before the 1kg ball. As many of these claims were unsupported it was difficult to ascertain what approach many of the students used, but there was clear evidence that both of those to be described below were used.

The second approach concerned the effects of air resistance. These responses tended to emphasise that the difference in time would be slight, but noticeable, as illustrated in this response:

"They take almost exactly the same time (difference due to air resistance)".

Although air resistance was used as a reason and the time difference small, the way it was used to explain the situation varied considerably from student to student, indicating that this was also an area of some confusion, that could well be investigated in its own right.

The third approach concerned the pull of gravity on the objects. The reasoning was that the greater the mass, the greater the gravitational force acting on it, as in this response:

"The 1kg ball will hit after the 3kg ball, because the gravitational pull is acting on only 1kg instead of 3kg".

With this type of response there was no emphasis on a small difference, and it was possible that it was this type of reasoning that led to the inversely proportional approach. However this is speculation and would need further investigation to confirm it.

These students who had the lighter mass landing first seemed to have very confused ideas about gravity, which were not possible to classify. One of these even described how gravity was pushing the balls upwards.

Responses	Percentage of Students
Balls land together, taking longer to fall	27%
Balls land together, no mention of time	32%
3kg lands first, taking longer to fall	15%
3kg lands first, no mention of time	11%
Both balls float away	8%
Other / no response	5%
Sample size = 202	

Table 94- Summary of Student Responses to Part Two of Question 9

As the students scripts were being marked and student responses recorded it became clear that the students reasoning was not consistent on both parts of this question. The results of a further examination, comparing responses to the first and second parts of the question are shown in Table 95.

		On Earth	
		Land together	3kg Lands first
On the Moon	Land together, in longer time	28%	1%
	Land together, no mention of time.	12%	15%
	3kg lands first, in longer time	1%	18%
	3kg lands first, no mention of time	9%	3%
	Balls float	2%	6%
	Other responses	6%	
Sample size = 200			

Table 95 - Comparison of Student Responses to the Two Parts of Question 9

From the distribution of the students responses shown in the table it is possible to identify six categories of response, which cover almost all the responses given. Examination of the responses in each category allowed conclusions to be drawn about the way that these students understand the concept of gravity. It has been attempted to arrange these categories so that the first ones represent the student with the better understanding of the concept of gravity.

The first of these categories, formed by 28% of the sample, contained the students who said that the balls would land together, in both situations, but that the time taken to fall would be longer on the moon. This response clearly represented a good understanding of gravity and the differences between it on different planets.

The second category responded in a similar way to the previous category, but failed to mention the difference in the times taken on earth and on the moon. This response was given by 12% of the sample. These students again had a good understanding of the concept of gravity, but did not appreciate that its magnitude can vary in different situations.

The third category consisting of 9% of the sample gave a correct response when on earth but on the moon expected the heavier ball to land first. There did not seem to be any consistent justification for this type of reason, but it was clear that the students viewed gravity on the two planets as being different. This group of responses came from students who appeared to have a good intuitive understanding of gravity on earth, but found it difficult to deal with the concept in an unfamiliar situation.

Forming the fourth category were 15% of the students. They stated that the heavier ball would land first on earth, but that they would land together on the moon. Their reasoning was obvious as can be seen in this response:

"They would be affected by weightlessness so they should be the same".

Clearly as the balls were considered to be weightless on the moon, they fall at the same rate. These students have little or no understanding of the concept of gravity, and are particularly confused about weightlessness, being unaware of the difference between weight and gravity.

The fifth category, composed of 18% of the sample, predicted that the heavier ball would land first in both situations. However, to their credit, they did say that they would take longer to fall. This group clearly had their own interpretation of the effects of gravity, but were aware that it was weaker on the moon.

Finally forming 8% of the sample were the students who denied the existence of gravity on the moon. Regardless of their response to the initial situation, they

explained that on the moon the balls would not fall and would simply float, as illustrated in this response:

"The balls would not fall as there is no force of gravity, pulling them downwards".

Although a few of these students gave the correct response to the first part of the question, it appeared that these students lacked even a reasonable intuitive understanding of the concept of gravity, in an unfamiliar situation.

Further evidence of poor understanding of gravity was evident in the students' responses to the question on the acceleration of the ball discussed in the acceleration section. Another question later on the paper that concerned the weight of an object on the moon, revealed that about 15% of the sample thought that it would be weightless.

In conclusion there was strong evidence both that student understanding of gravity on earth and their ability to consider gravity in other situations, was much weaker than would be expected. These results made the assumption, that students already have an understanding of gravity, unrealistic.

8.7 Projectile Motion

Projectile motion was the final topic to be included in the test. Whitaker (1983) has described the problems that college students have encountered with projectile motion. Falling under the influence of gravity has already been discussed in the previous section, but there the emphasis is on the motion of objects that have an initial velocity.

There were four questions on the test that examined this case. The first of these was question 8.

8. On a bombing run a plane approaches its target along a straight line at constant speed. If the plane maintains this course where is it when the bombs hit the target?

The responses to this question are recorded in Table 96.

Response	Percentage of Students
Above bomb	29%
In front of bomb	50%
In front of bomb (due to air resistance on bomb)	10%
In front of bomb (because bomb falls straight down)	5%
Other / no response	6%
Sample size = 206	

Table 96 - Summary of Student Responses to Question 8

It was clear that although some students were able to predict the paths of the bomb and the plane, the majority were unable to do this or to justify their answers. From the arguments and diagrams that the students used to support their responses it became clear that there were two incorrect approaches taken to the problem.

The first of these was simply that the bomb falls straight down, with no horizontal motion, while the plane continues to fly along its straight path. Some of the students even attempted to predict the distance that the plane would travel along this line while the bomb was falling. A typical response of this nature was:

"Beyond the target allowing for time between release of bomb, descent time and time target hit. If the bomb took 3 secs to reach target the plane would be 3 secs worth of distance away".

Thus these students did not realise that the bomb would initially have a velocity, the same as the velocity of the plane at the instant of release.

The second approach had a strong resemblance to some of the responses to the second part of the spaceship question, discussed in the section on force and Newton's laws. There they said that when the engines were switched off the spaceship would slow down, here the students predicted that the bomb would begin to slow down as soon as it leaves the plane. Very few students attributed this slowing down to a force, such as air resistance, but seemed to imply that it was a characteristic of the motion of the bomb. So these students state that the bomb lands just behind the plane, as illustrated in this response:

"Just past the target, as the bombs slow down after release".

These students had taken the step of realising that the initial velocity of the bomb was the same as the velocity of the aircraft, but did not feel that the horizontal component of this velocity could be maintained once the aircraft was no longer causing the bomb to move. Although they do not mention the horizontal component of velocity explicitly, it was clear that this was what they are considering.

There was the possibility that some of these students were considering the effects of air resistance on the bomb, and in fact 10% had explained this in their responses. However from the diagrams drawn by some of the 50%, it was

unlikely that air resistance could have been the reason that these students reached their conclusions.

The path of a projectile launched from ground level was considered in question 6.

6. A cricket ball is thrown into the air with an initial velocity shown by the arrow in the diagram. Sketch a possible path of the ball, from the point O where it is launched to the point where it bounces for the first time.

If you were to decrease the angle without altering the magnitude of the velocity, what would happen to the horizontal distance travelled by the ball?



Figure 45 - The Diagram for Question 6

The responses to the first part of question 6 are recorded in Table 97 and for the second part in Table 98.

Responses	Percentage of Students
Approximately parabolic path	9%
Path initially along initial velocity vector followed by parabolic path	69%
Other / no responses	21%
Sample size = 202	

Table 97 - Summary of Student Responses to Part One of Question 6

The paths drawn by the students generally had a strong resemblance to a parabola. However the most interesting and unexpected aspect of the response to this question was the way that the vast majority of the students included the initial velocity vector as part of the path. It seems that the students felt that the projectile was compelled to follow the arrow, but did not explain why. It can be assumed that the students do not really understand the term initial velocity and that they are unable to apply a valid meaning to it.

The 21% of the responses that did not resemble parabolas were either very unsymmetrical or almost triangular in appearance.

Responses	Percentage of Students
Range increases, then decreases	7%
Range increases	85%
Others / no response	7%
Sample size = 148	

Table 98 - Summary of Student Responses to Part Two of Question 6

From Table 98 it was apparent that the majority of students expected the range to increase as the angle is decreased, but only very few realised that it will then decrease. A further question on the range of a projectile revealed that very few students had any understanding, even at an intuitive level, of the idea that two different angles of projection could give rise to the same range.

In concluding this section it is interesting to note that although most students recognise that the path of a projectile will be parabolic there are other significantly more difficult ideas associated with this topic. The role of initial velocity is one that the students often ignore or fail to understand. Similarly the relationship between range and angle of projection is unfamiliar, even at a very intuitive level.

8.8 Conclusion

As the students had received no formal teaching of mechanics, with the exception of an introduction to kinematics, their responses to the questions must be based on their existing knowledge. This could have originated from one or both of two sources. The first of these is their experience of life, where they are surrounded by the motions and situations that mechanics describes. The second was from their classroom learning experiences, most probably in physics. From these two sources and particularly from the first the students will have assimilated meaningful concepts into their cognitive structures, even though, as the results have indicated, many of them were at conflict with scientific concepts. A major difference between this study and those undertaken by physicists is that some of the students would never have been taught physics and a significant proportion would not be studying physics at A-level.

It is important to examine the errors in the students responses in order to establish the differences between the students concepts and the scientist or mathematicians concepts. The errors on the test paper can be broadly classified into two different types. Firstly, there were the responses that indicated an incomplete understanding of a concept, for example a student may understand velocity as a one dimensional concept, but be unable to use it in two or three dimensions. In this situation there is nothing wrong with the students viewpoint, but it simply does not embrace the concepts full meaning. Secondly there are responses that indicate an understanding that is fundamentally different to the mathematicians view, for example the view that a net force is needed to maintain motion. Here the student interprets a concept in a way that is not acceptable to the mathematician, often referred to as a misconception or preconception.

Two different teaching approaches are needed to overcome these two different types of error. For the first the students view of the concept needs to be extended to include its full meaning. However for the second type of error the students existing beliefs have to be challenged and shown to be inadequate before a new approach can be developed. The teaching method that is to be utilised will depend on the understanding of the students in that particular class, but this report provides a guide to the type of understanding that a teacher can expect. Thus this chapter forms a base on which the teaching of mechanics could be developed. The importance of taking account of students existing beliefs has been described at length by Gilbert et al. (1982). If students incorrect ideas are not challenged and displaced, then a course of instruction may leave them unchanged or even be used to strengthen them. Imagine how convinced a student who follows a sixth form course on mechanics feels about his misconceptions if they are still intact at the end of the course! Another alternative is that the student develops two separate approaches to mechanics, a major one that he applies to the world around him and a minor one for the world of the mechanics textbook. The type of preconceptions described by Clement (1982) and others exist in undergraduate students because they have remained unchallenged.

During the process of gathering the data for this survey it became clear that some of the teachers, whose classes were tested, were very surprised to discover the responses that some of their students gave to some questions. The type of informal remarks made, clearly indicate that there is a discrepancy between what teachers expect their students to think and what they actually do think. It would certainly be interesting to take this further to examine the extent to which teachers are aware of their students level of understanding.

Chapter 9 - A Hierarchical Model of the Development of Student Understanding of Force

9.1 Introduction

When the first post-test was administered to the Exeter College students as part of the video evaluation experiment the students' scripts were marked to provide scores for use in the statistical analysis. However they also provided a wealth of information about the students understanding of the concepts under consideration. Thus an opportunity existed to look more closely at student understanding. Past studies such as that of Roper (1985) and Helm (1980) have identified the errors that students make while others such as Trowbridge and McDermott (1981) have attempted to categorise students' approaches and identify groups of students from these. By extensive work with secondary school children through the CSMS programme, Hart (1981) has identified levels or stages through which students' understanding of secondary mathematics concepts develop. It is an approach adapted from the CSMS work that has been adopted here to examine the way in which student understanding of force and its relationship with motion develops. This approach goes beyond the existing research in two ways. First it shows how the CSMS methodology can be applied to students understanding of other areas and levels of mathematics. Secondly it defines a set of levels that would model the development of student understanding, rather than simply identifying some of the problems that students have in their understanding of mechanics.

The first post-test taken by the students at Exeter College in the first year of the video experiment was used to carry out a pilot investigation. An analysis was successfully carried out leading to the identification of three stages in the

development of student understanding of force. This clearly demonstrated the feasibility of adapting the CSMS approach to the data gathered for mechanics concepts at this level. As these results were based on a very small sample compared to the CSMS work and all the students were taken from the same institution the results of the pilot study had to be regarded with caution. To extend the work and to attempt to validate the initial model of the development of understanding a much larger scale survey of student understanding was undertaken. This chapter describes the methods used to identify the stages in the development of understanding, the pilot investigation, the levels that were formed as a result of the larger scale study as well as the resulting implications of the results for the classroom teacher.

9.2 The Method Used to Form the Levels of Understanding

A simple approach to the formulation of levels would have been to group together all the questions that had a similar degree of difficulty. The questions in each group could then be used to define a level of understanding. However there would be no certainty that such a model would be scaleable, i.e. that success on a higher level required success on all lower levels. Examination of research revealed the approach taken by Hart (1981) for the CSMS work. Not only had this method been applied successfully to several areas of the secondary mathematics curriculum, but it had also been selected for this purpose after a careful study of the alternatives available, Hart (1980).

Each level was to consist of a set of test questions from which in conjunction with the students responses a detailed description of their understanding could be derived. Based on the work by Hart a set of criteria was selected which the questions forming the model of the development of understanding should satisfy. These criteria are listed below.

(i) The test questions forming each level should have similar degrees of difficulty, i.e. the questions on any one level should be answered correctly by a similar proportion of the students.

(ii) Success on one question on a level should be associated with success on every other question on the same level. This association was to be measured with the product-moment correlation coefficient for dichotomous data, phi. Details of this coefficient are given in appendix D.

(iii) Students should not reach any level without passing all the lower levels. In practice this may not be possible but the number of students not complying to this criteria should be small.

(iv) There should be a degree of sense to the levels with regard to their content from a mechanics viewpoint.

In practice it was necessary to develop a procedure for the analysis of the data that would allow these criteria to be met. The steps described below form the procedure that was used for the analysis.

(i) A scatter plot of percentage of students answering correctly against question number was prepared.

(ii) Values of the phi coefficient were computed and tabulated for every pair of test questions.

(iii) Using the data from step (ii) lines were added to the scatter plot of step (i), joining pairs of questions that had phi values greater than or equal to 0.3. This

value was selected because it provided a good number of links but did not initially overcrowd the plot.

(iv) Groups of questions were then extracted, the criterion for extraction being that every question in the group was linked to every other with a phi value greater than or equal to 0.3. It was also expected that each question in a group would have similar degrees of difficulty. Groups of questions that did not satisfy this second criteria would not be extracted.

(v) Other questions that had a phi value greater than or equal to 0.3 for most questions in the group were then added to it, again subject to the condition of having similar degrees of difficulty. Also other questions that had values of phi close to 0.3 were included.

(vi) By this stage a number of groups would have been formed, which contained questions at different degrees of difficulty. These groups were then tested for their scalability, that is that the students progressed through the levels of the hierarchy in order, without missing out a level. A student would be defined as not conforming to the model, if they passed a higher level without passing all the easier or lower levels. A pass mark for each level had to be defined, it should be high enough to ensure that the students who attain that level are able to answer most of the questions on the level, but not so high that students with a good understanding who answer one or two questions incorrectly fail to attain that level. For this study the pass mark was defined to be as close as possible to but not greatly exceeding 70%. This pass mark was very similar to that used in their CSMS work. The percentage of students not conforming to the model was then determined. Provided this proved to be low the model was considered to be acceptable in this respect.

(vii) The coherence of the levels from a mechanics viewpoint was then examined. At this stage some readjustment was possible, for example where a test question could equally well have been placed on one of two levels. If readjustment took place then step (vi) would be repeated to confirm the scalability of the model.

9.3 The Pilot Investigation

The main purpose of the pilot investigation was not to produce a definitive set of levels on which to base a model of conceptual development, but to investigate the feasibility of using the methodology described in section 9.2 with the questions developed for the tests of understanding described in chapter 5. A set of hierarchies was developed and there are strong similarities between this and the final set obtained from the larger scale survey described in section 9.4.

The data on which the pilot investigation was based was obtained when the students involved in the video experiment at Exeter College completed the first pre-test for the force topics in block 1 of the original version of the teaching package. This sample contained only 55 students, a very small number when compared with the work of Hart (1981). However it was considered that if the outcome of the investigation was promising then the use of the questions in larger scale experiment would be justified. The procedure described in section 9.2 was followed with the data and three levels were identified, with those students not attaining level 1 being assigned to level 0. When the resulting model was examined to see if it satisfied the five criteria described in section 9.2 there were found to be no problems, in fact there were no students in the sample who did not conform to the scalability criterion.

The abilities demonstrated by the students reaching each of the levels identified have been described below.

Level 1

To achieve an understanding at level 1 the students should be able to;

- (i) identify that the forces acting on a particular body are in equilibrium if it is at rest or moving with a constant velocity,
- (ii) understand that if all the forces acting on a body are removed it will move with constant velocity,
- (iii) find the force necessary to make a stationary body move in a specified direction when one force is already acting,
- (iv) predict the path of a moving object after a force has been applied to it for a short time.

Level 2

To achieve an understanding at level 2 the students should be able to;

- (i) describe what happens to the velocity and acceleration of a moving body when a constant force is applied to it,
- (ii) know that the acceleration of an object is zero when no forces are acting,
- (iii) understand the conditions under which a body moves with constant speed,
- (iv) understand the effects of gravity on objects that are initially stationary,
- (v) should be aware of the importance of the point of application of a force.

Level 3

To achieve an understanding at level 3 the students should be able to;

- (i) describe the acceleration of an object that is subjected to a variable force,
- (ii) describe how variable mass affects the velocity and acceleration of an object, which is acted on by a constant force,

(iii) identify the resultant force on an object when it is not in the direction of motion,

(iv) understand the effects of gravity on any object.

The distribution of students to these levels is shown in Table 99, along with the pass mark required for each level.

Level	Percentage of Students	Pass mark
0	31%	
1	31%	71% (5/7)
2	24%	63% (5/8)
3	15%	70% (7/10)

Table 99 - Distribution of Students to the Levels of the Hierarchy

A model of this type should be useful to teachers as it identifies the stages through which they can expect their students to pass as their understanding improves. The content of level three is beyond those students who have not mastered the ideas of the lower levels. For example it is unrealistic to expect students to solve problems where gravity acts on a moving object (level 3) when they do not understand how gravity acts on an object that is initially at rest (level 2). It provides teachers with an ordered set of expectations which they can ensure are mastered before progressing to more advanced work. This can be used in conjunction with the research on the intuitive ideas that students have, since it can be these intuitive ideas that hold up the transition from one level to the next. For example the force in the direction of motion misconception would prevent students progressing to level three. One possible resource, which would be of assistance to teachers, that could be developed from the results of this research is a diagnostic test that could be used to ascertain the level to which students understanding had progressed.

When looking at this part of the research it must be noted that the sample it was based on was small and came from only one institution. Thus it must be regarded with caution and is best thought of as a feasibility study for investigating the potential of the methodology, rather than for producing a set of results.

The application of this method of analysis to data of this type has been successful in achieving its objective of identifying a set of levels that will form a hierarchical model for the development of student understanding. In the light of the success of this pilot investigation it was decided to go ahead with a larger scale survey in order to produce a more reliable set of levels. The test initially used as the post test at Exeter College was adjusted slightly in the light of the results obtained here, deleting questions that had shown very low levels of associativity with other questions and replacing them with questions similar to those that had been included in the pilot model. It was anticipated that this would help in the formation of the levels in the larger scale survey.

9.4 Results of the Large Scale Survey

9.4.1 The Large Scale Survey

The initial investigation carried out in early 1989 had suggested that it would be possible to develop a set of hierarchies, based on the responses of 50 students to a questionnaire that they had completed. It was with a view to validating and refining the results of this initial investigation that a larger scale survey was initiated. During the summer term of 1989 schools and sixth form colleges were invited to take part in the larger scale survey, with students completing questionnaires during July or September. A good initial response was supported well by a high level of return of the completed questionnaires. A total of 632 student questionnaires were completed and returned for use in the analysis of the

results. The participating students were all studying A level mathematics and drawn from a wide range of backgrounds including public, comprehensive and grammar schools as well as sixth form colleges.

The analysis of the results led to the formulation of a model of the development of student conceptual understanding. This model consists of three levels through which student understanding passes as it develops. The students were allocated to one of these four levels with those not attaining the lowest level being assigned to a level 0. The model fits the survey results well with only a very small proportion of students not conforming to it.

This section begins with a description of the evidence used in the formation of the levels. For each of the three levels the questions that were used to form the level are then given along with a description of the students abilities and the misconceptions and strategies that the students adopted at each level. In addition the strategies used by the level 0 students are described.

9.4.2 The Formulation of the Model of Conceptual Development

The process used to form the levels has been described in section 9.2. Here the criteria of section 9.2 are presented with evidence to support the formulation of the levels constituting the model of conceptual development.

(i) The questions forming the level should have similar degrees of difficulty, i.e. the questions on any one level should be answered correctly by a similar proportion of the students.

Clearly not all the questions on a level would be likely to have exactly the same proportion of the students giving correct responses, so for each level there would be a range of difficulty rather than a single value. These ranges are given in Table 100.

Level	Interval	Range
1	65-85%	20%
2	55-76%	21%
3	23-47%	24%

Table 100 - Correct Response Intervals for Each Level

It should be noted that there is some overlap of the intervals for levels 1 and 2, but that for level 3 there is none. The sizes of the intervals are all very similar ranging from 21 to 25%. Since there are no anomalies here the first criterion is clearly satisfied.

(ii) Success on each question in the level should be associated with success with the other questions in the level. This association was measured using phi, the product moment correlation coefficient for dichotomous data.

As the phi coefficient was the major tool used in the identification of the questions to form each level there should be few problems in satisfying the second criterion. It should be noted that there were many more and stronger links with the harder questions than with the easier ones. For this reason it can be observed that the phi values are higher for levels 2 and 3 than for level 1. Tables 100, 101 and 102 give the values of the phi coefficient for each of the levels, while Figures 46, 47 and 48 illustrate these links.

These tables and figures illustrate that there is a high degree of association between the questions on each level, thus satisfying criterion (ii).

	1(v)	3(i)	5(ii)	6(i)	6(ii)
1(ii)	.624	.162	.193	.099	.188
1(v)	-	.190	.252	.120	.224
3(i)	-	-	.305	.212	.329
5(ii)	-	-	-	.304	.519
6(i)	-	-	-	-	.435

Table 101 - Phi Values for the Level 1 Questions

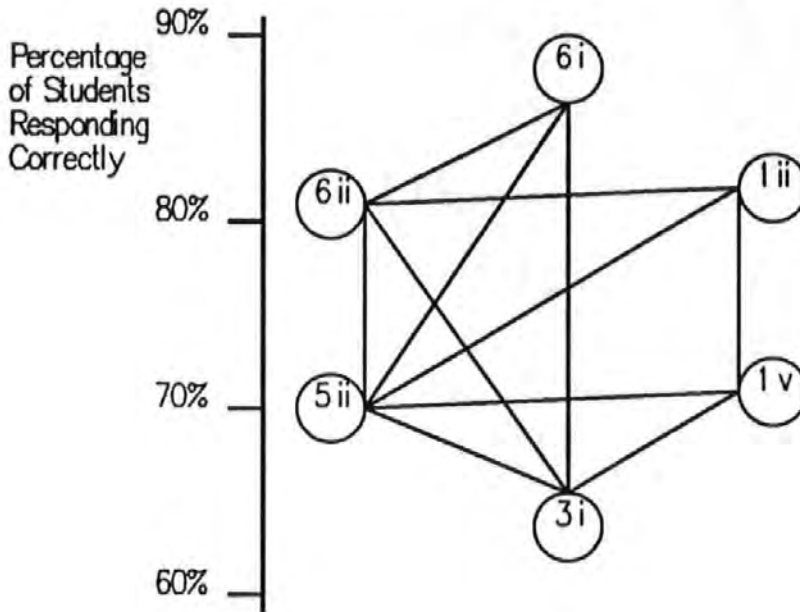


Figure 46 - Phi Links Greater Than 0.180 For Level 1

	8ii	10	18ii	18iii	18iv	18v	20i	20ii	22ii
7	.367	.336	.302	.404	.345	.269	.131	.156	.178
8ii	-	.320	.242	.318	.269	.227	.129	.276	.137
10	-	-	.336	.352	.471	.442	.214	.393	.305
18ii	-	-	-	.471	.369	.356	.160	.193	.209
18iii	-	-	-	-	.524	.487	.206	.295	.229
18iv	-	-	-	-	-	.727	.310	.324	.344
18v	-	-	-	-	-	-	.297	.344	.359
20i	-	-	-	-	-	-	-	.306	.277
20ii	-	-	-	-	-	-	-	-	.270

Table 102 - Phi Values for the Level 2 Questions

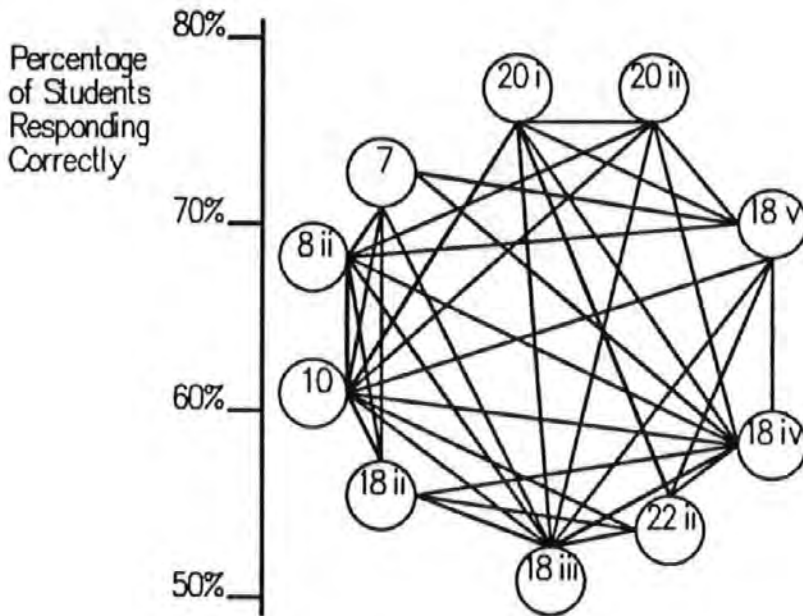


Figure 47 - Phi links Greater Than 0.200 for Level 2

	liv	4C	4D	4E	4F	4G	13iA	13iB	13ii	15A	15B
liii	.312	.186	.193	.213	.303	.215	.229	.225	.211	.151	.138
liv	-	.353	.322	.308	.184	.379	.492	.399	.392	.291	.277
4C	-	-	.407	.333	.190	.408	.376	.302	.274	.226	.236
4D	-	-	-	.732	.388	.754	.398	.351	.330	.286	.288
4E	-	-	-	-	.347	.766	.457	.348	.340	.313	.308
4F	-	-	-	-	-	.373	.209	.210	.151	.132	.132
4G	-	-	-	-	-	-	.522	.433	.415	.345	.357
13iA	-	-	-	-	-	-	-	.630	.591	.360	.360
13iB	-	-	-	-	-	-	-	-	.534	.287	.290
13ii	-	-	-	-	-	-	-	-	-	.379	.377
15A	-	-	-	-	-	-	-	-	-	-	.965

Table 103 - Phi Values for the Level 3 Questions

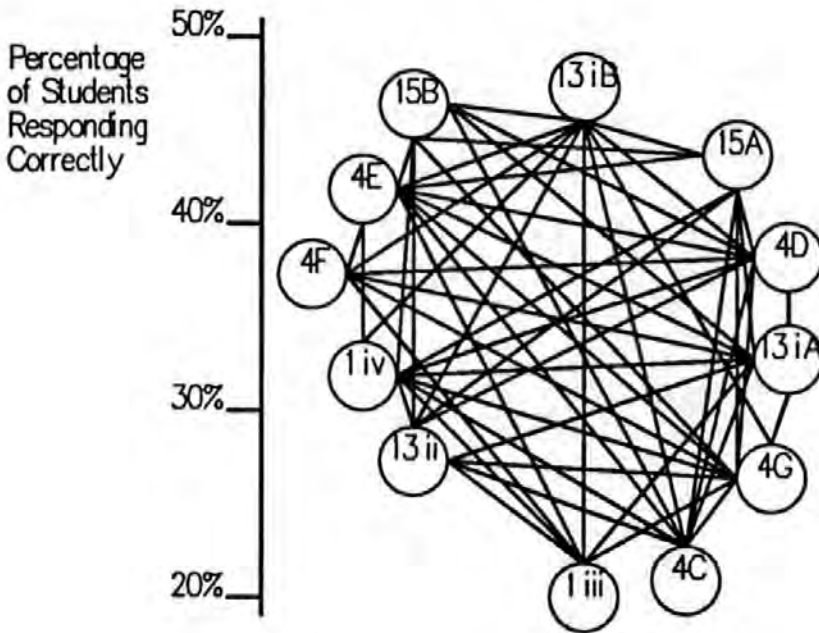


Figure 48 - Phi Links Greater Than 0.200 for Level 3

(iii) Students should not reach any level without passing all the lower levels. It would only be acceptable for a very small proportion of the sample to attain a level without being successful on all the lower levels.

The analysis led to the formation of three levels, with those students not attaining any of them being classified as level 0. To succeed on a level each student was required to answer a certain number of questions correctly. The pass

mark for each level was defined to be as close as possible to, but not exceeding 70%. Table 104 shows the distribution of students to levels and the pass mark assigned to each level.

Level	Percentage of Students	Pass mark
0	20%	
1	25%	67% (4/6)
2	30%	70% (7/10)
3	25%	67% (8/12)

Table 104 - Distribution of Students to the Levels of the Hierarchy

There were a number of students who attained levels without attaining all the lower levels. However these students only accounted for 6.2% of the whole sample. Thus the vast majority of the students conformed to the model.

(iv) There should be a degree of sense to the levels with regard to their content from a mechanics viewpoint. The abilities of the students reaching each of the levels are described below.

Level 1

To achieve an understanding at level 1 the students should be able to;

- (i) identify that the forces acting on a particular body are in equilibrium if it is at rest or moving with a constant velocity,
- (ii) predict the motion of an object when it is subjected to a constant force for a specified period of time,
- (iii) understand that if all the forces acting on a body are removed it will move with constant velocity,
- (iv) understand the effects of gravity on objects that are initially at rest.

Level 2

To achieve an understanding at level 2 the students should be able to;

- (i) predict the motion of an object when it is subjected to a total non-zero constant force for an undefined period of time,
- (ii) describe what happens to the velocity and acceleration of a moving body when a constant force is applied to it,
- (iii) state that the acceleration of a body is zero when no forces are acting on it,
- (iv) understand the conditions under which a body moves at constant speed.

Level 3

To achieve an understanding at level 3 the students should be able to;

- (i) identify the forces acting in a wide variety of situations,
- (ii) identify the resultant force on an object, when it is not in the direction of motion,
- (iii) demonstrate a complete understanding of the idea of equilibrium,
- (iv) understand the effects of gravity on an object in any initial situation.

This summary shows that there is a meaningful development through the levels of the hierarchy, which satisfies criterion (iv). In sections 9.4.3, 9.4.5, 9.4.7 and 9.4.9 the levels are described in more detail. These sections also illustrate a meaningful progression in the development of the students understanding.

Thus the set of levels formed satisfies all the criteria that were set out at the beginning of the investigation.

9.4.3 Description of Level 0

The level 0 students have many problems with the basic concepts of mechanics, some of which are shared by the level 1 and 2 students. However there are some

misconceptions which are used almost exclusively by the level 0 students, and it is these that are described here while those common to the other levels are dealt with later on.

One of the most significant incorrect approaches taken by the level 0 students is to assume that a force is necessary to maintain motion. This is clearly identified by their responses to questions 1(ii), 1(v), 5 and 6.

When responding to question 1(ii) 62% of the level 0 students gave unacceptable responses, with 54% stating that the forces acting on the motorbike were not in equilibrium. A significant 51% of the level 0 students also stated that the resultant force was acting in the direction of the motion of the motorbike. For question 1(v) a greater proportion of the level 0 students responded in this way. Here only 17% stated that the forces acting on the parachutist were in equilibrium, with 67% stating that they were not in equilibrium. A force in the direction of motion was specified by 67% of the level 0 students who felt that the net force was acting downwards. For the two parts of question 1 the motion is described as having constant speed but in answering both parts the majority of the level 0 students stated that the bodies concerned were not in equilibrium and that there was a force in the direction of motion. These responses indicate the presence of an expectation that a net force is required to maintain motion and that equilibrium can only be achieved when there is no motion.

The idea that a net force is needed to maintain motion is also clearly expressed in their responses to questions 5 and 6. Here although a fair proportion of them correctly stated that the speed would increase while the force was applied, the vast majority expected that the speed of the body would decrease rapidly once the force was removed. For question 5(ii) 78% of the level 0 students gave unacceptable responses with 66% stating that the puck, X, would slow down.

Similarly for question 6, 64% gave unacceptable responses for the speed of the rocket after the forces were removed, with 57% stating that the rocket would slow down. They assume that once the force, that was in their view maintaining the motion, is removed the body will slow down and stop.

Their ideas about gravity are also weak, demonstrated by their responses to question 3(a), of which 74% were unacceptable. Here they expected gravity to have a greater effect on heavier objects than lighter ones, with 69% of the level 0 students stating that the 3kg ball would land first. They appreciate that gravity will exert a greater force on a greater mass, but do not realise that this will cause the same acceleration. One particular error that a significant number of students adopted was to assume that the time taken for the balls to fall to the ground would be inversely proportional to the mass of the balls. In fact 47% of the level 0 students stated that the 3kg ball would fall in $\frac{1}{3}$ of the time taken for the 1kg ball to fall.

In addition they experienced further problems in common with the level 1 students on the level 2 and 3 questions, and the level 2 students on the level 3 questions. These difficulties are described in the appropriate sections.

To summarize the level 0 students have a very weak understanding of the relationship between force and motion expecting force to maintain rather than to change motion. Also their understanding of key concepts like gravity are confused.

9.4.4 Questions Forming Level 1

1. For each of the following situations, state whether the forces acting are in balance (equilibrium). If they are not, then state in which direction the resultant or overall force on the object is acting.

(ii) A motorbike travelling at a steady 60 mph along a straight road.

(v) A parachutist, who is falling at a constant rate.

3. Two balls are exactly the same size and shape, but have masses, of 1kg and 3kg. They are dropped at the same time from the same height.

(i) How does the time that they take to fall to the ground compare?

5. The diagram below shows an air puck, X, hovering on a smooth glass table and connected by a string running over a friction-less pulley to a mass, Y. When Y is released it pulls X across the table.

(ii) When the air puck, X, reaches the point B the string breaks, what happens to the speed of the puck after it passes point B ?

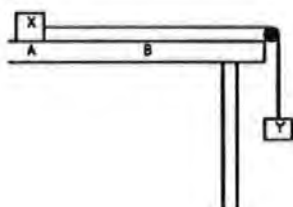


Figure 49 - Diagram for Question 5

6. A spaceship is stationary in deep space. It fires its engines so that they exert a constant force for a two minute period and are then turned off. On the axes below sketch a graph of speed against time for the motion of the spaceship.



Figure 50 - Diagram for Question 6

9.4.5 Description of Level 1

Those students who have reached level 1 have, unlike the level 0 students, begun to come to grips with the idea of equilibrium, recognising that when a body has uniform motion it is in equilibrium. In question 1(ii) 98% correctly stated that the forces acting on the motorbike were in equilibrium. Similarly in question 1(v) 88% recognised that the forces acting on the parachutist were in equilibrium. In both these cases they were also able to state that there was no resultant force present. However they do have difficulty, as do the level 0 students when a body is instantaneously at rest, such as a bouncing ball at its lowest point, in question 1(iii) or a ball thrown up into the air vertically at its highest point, as for position B in question 13. For question 1(iii) 69% of the level 0 and 65% of the level 1 students considered that the forces acting were in equilibrium. Similarly for question 13 when the ball was at its highest point, 61% of the level 0 and 52% of the level 1 students stated that the forces acting were in equilibrium. In these situations both the level 0 and level 1 students tend to associate the zero velocity or speed with equilibrium, even though the motion of the body is being subjected to change. Although the students were able to

recognise equilibrium they were unable to describe how to set a body in motion at constant speed. This problem is illustrated by the majority of level 0 and level 1 students being unable to answer question 10 correctly, with 83% of the level 0 and 64% of the level 1 students failing to describe a suitable strategy. Here most of the incorrect responses to this question suggested that the students reverted to considering a constant force to be necessary to maintain the motion. This is a strategy that appears in other situations where these students reasoning does not cope with the problem.

They also are able to describe the effect on the speed of the body of applying a force to a body for a short fixed time and removing that force. Questions 5 and 6 were answered well the students on level 1 with 61% giving acceptable responses to question 5(i) and 73% giving acceptable responses to question 6, correctly stating that the speed increases while the force is applied but remains constant when the force is removed. However they are less sure when the force is applied for an undefined period of time, as in questions 7 and 8. Unacceptable responses came from 51% of the level 1 students on question 7 and 55% on question 8(ii). They seem unable to accept that the speed will increase indefinitely unless the force is removed. Their expectations are that the force will result in a constant speed or one that increases until it reaches a maximum value determined by the force. These students were unable to justify these responses with an air resistance argument that was used by some of the students on the higher levels. Again they seem to be reverting to force to maintain motion misconception when faced with a situation that they are not able to deal with.

Finally these students have a good idea of the effects of gravity on initially still objects expecting them to fall at the same rate, as in question 3(a), where 67% of the level 1 students stated that the two balls would fall in the same time. However they are unable to identify the force of gravity in other situations. For

example when it is not the cause of the initial motion of the body, as in question 13. In this question 52% of the level 1 students expected there to be no net force when the ball was at its highest point and 67% expected there to be a net upward force when the ball was moving upwards.

To summarize the level 1 students have some simple ideas about force and motion, but their understanding of the relationship between force and motion is incomplete. They also have great difficulty identifying forces and expect them to act in the direction of motion or to be zero if the body under consideration is instantaneously at rest. There is still a strong link in their reasoning between the concepts of force and velocity, rather than the rate of change of velocity, and little awareness of the concept of acceleration.

9.4.6 Questions Forming Level 2

7. An object is resting on a smooth level surface when a force is applied to it. What happens to its velocity if the force is not removed ?

8.(ii) When these two forces act simultaneously on the puck, what happens to its speed ?

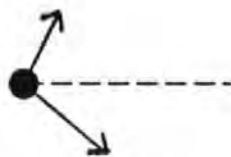


Figure 51 - Diagram for Question 8

10. An air puck is hovering on a glass table, where it experiences no friction when it moves. What would you do to it, to make it move with a constant non-zero velocity if it is initially stationary?

18. Deep in outer space a spacecraft is stationary. It fires its engines in such a way that they exert a force that increases uniformly in magnitude from zero to 5000 N over a five minute period.

After this initial period the engines exert a constant force of magnitude 5000 N for a further five minute period. What happens to the magnitude of;

(ii) the acceleration,

(iii) the velocity, during this period ?

The engines are then switched off. What now happens to the magnitude of;

(iv) the acceleration,

(v) the velocity ?

20. You are looking down from above on a spiral tube resting on a horizontal table. A ball is shot into the tube at a high speed.

(i) Draw the path of the ball when it leaves the tube.

(ii) What happens to the speed of the ball as it moves across the table after it has left the tube, if the effects of friction and air resistance are negligible



Figure 52 - Diagram for Question 20

22. A rocket is drifting sideways in deep space from A to B, with its engines off and no forces acting on it. When it gets to B it fires its engines, providing a constant force until it reaches C, when the engines are turned off. On the diagram below draw a possible path for the rocket;

(ii) from C onwards.



Figure 53 - Diagram for Question 22

9.4.7 Description of Level 2

The level 2 students are able to extend the ideas of the level 1 students and can demonstrate the ability to give a fuller description of the relationship between force and motion. They are able to answer problems where they predict the effects of varying the applied force on motion in one dimension, being able to predict the effect on both velocity and acceleration in question 18. Their responses to the parts of this question are summarized in Table 105. These results illustrate how the level 2 students have overcome the constant / maximum speed misconception that the level 1 students experienced and are able to relate force to an increasing speed, for the situations given in questions 7 and 8, where the force was applied indefinitely. For these two questions 91% and 83% of the level 2 students respectively gave acceptable responses.

Question	Percentage of Students Giving Acceptable Responses
18(i)	79%
18(iii)	85%
18(iv)	94%
18(v)	97%

Table 105 - Responses of the Level 2 Students to parts of Question 18

In two dimensional situations, found in questions 20 and 22, they are able to apply Newton's first law but have much more difficulty with the interpretation of the effects of a force on the motion of a body. When a force is removed they are able to indicate that a body will continue to move in a straight line at constant speed, at a tangent to a curved path. For question 20(i), 85% of the level 2 students drew a tangent to the curve, and for question 22(ii), 69% of the students drew a line that was at a tangent to their answer to 22(i). The lower degree of success was due to some of the unusual responses given to 20(i). When a constant force is applied in two dimensions but is not parallel to the

path they are unable to predict the subsequent motion. Their responses to question 22(i), where 46% of the level 2 students drew straight lines from A to B, suggest that they expect the force to change the motion instantaneously and not during the period for which the force acts.

There is evidence, from questions 7, 8 and 18, where the motion is restricted to one dimension, that these students do not assume that there must be a force in the direction of motion. However when they encounter motion in two dimensional situations they again revert to using this misconception. This appears particularly in questions in which the direction of motion is clearly identifiable, such as questions 4, 13 and 15. Table 106 gives a summary of the students responses to questions 4 and 13 which clearly illustrate that these students expect there to be a force in the direction of motion. For question 15 acceptable responses were given by 41% and 42% of the level 2 students for positions A and B respectively. Many of the unacceptable responses included forces in the direction of motion but were difficult to classify due to the wide range of combinations of forces produced.

Question	Acceptable Response	Force in Direction of Motion Response
4C	15%	69%
4D	23%	52%
4E	24%	69%
4F	23%	22%
4G	15%	61%
13A	27%	59%
13B	34%	56%*
13C	89%	89%

* Zero force acting.

Table 106 - Summary of Level 2 Students Responses to Questions 4 and 13

Their understanding of gravity is similar to that of the level 1 students. They still have difficulty identifying the forces acting on a body moving under the effects

of gravity that was not initially at rest, as in question 13. Here they expect there to be a force in the direction of motion, even when this is in the opposite direction to which gravity is acting. They are unable to accept that gravity can be the only force acting on a body that is not falling downwards.

With regard to equilibrium they still have the same difficulty as the level 1 students in that they expect an object that is instantaneously at rest to be in equilibrium. Responding to question 1(iii), 63% of the level 2 students stated that the forces acting on the ball were in equilibrium. They have progressed to the stage where they are able to describe how to make an object move with constant velocity, as required in question 10. This question was correctly answered by 84% of the level 2 students demonstrating a stronger link between force and equilibrium rather than speed and equilibrium. This step forward again suggests that the students have overcome the misconception that a force is required to maintain motion, when the motion is restricted to one dimension.

To summarize the level 2 students have progressed to link their ideas of force to acceleration rather than directly to speed or velocity, considerably improving their understanding of the relationship between motion and force. Their ideas of equilibrium still have weaknesses as does their understanding of gravity. For motion in two dimensions they have some simple ideas, but these are limited and in most situations they expect there to be a force acting in the direction of motion.

9.4.8 Questions Forming Level 3

1. For each of the following situations, state in which direction the resultant or overall force on the object is acting.

(iii) A bouncing ball while it is in contact with the ground.

(iv) The ball above just after it has bounced and is just clear of the ground.

4. The diagram shows the path of a ball as it first slides along a track and then moves through the air. Use one arrow to indicate the resultant force on the ball at each of the positions marked with a letter.

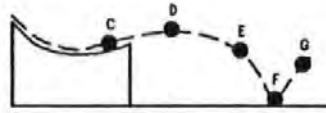


Figure 54 - Diagram for Question 4

13. A ball is thrown vertically, up in the air, as shown in the diagram. At A it is on its way up, at B it is at its highest point and at C it is on its way down.

(i) Draw arrows to show the direction of the force at the points A and B.

(ii) How does the magnitude of the force acting on the ball compare at each of these three points ?

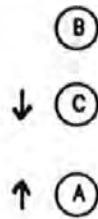


Figure 55 - Diagram for Question 13

15. The diagram shows a pendulum, which swings from left to right through the points A and B. Draw arrows to show the direction of the forces (ignoring air resistance) acting on the pendulum at each of these points. Describe each of the forces that you have indicated.



Figure 56 - Diagram for Question 15

9.4.9 Description of Level 3

The questions forming level 3 are almost exclusively concerned with the identification of the forces acting in various situation. The questions required students either to mark in the individual forces acting or the resultant force. The level 3 students had overcome completely the force in the direction of motion misconception and were able to identify correctly tensions, reactions and the force of gravity. This represented a major step forward from the level 2 students who could often identify some of the individual forces but who would also include a force in the direction of motion. The questions 1(iv), 4, 13 and 15 fall into this category, with the students responses to this summarised in Table 107. These results clearly show that the students have abandoned the force in direction of motion misconception.

Question	Acceptable Response	Force in Direction of Motion Response
1(iv)	83%	8%
4C	63%	10%
4D	97%	2%
4E	96%	3%
4F	67%	21%*
4G	93%	3%
13A	96%	3%
13B	96%	3%*
13C	97%	97%
15A	88%	-
15B	87%	-

* Net force zero.

Table 107 - Summary of Level 3 Students Responses to Questions 1(iv), 4, 13 and 15

The level 3 students were able to demonstrate that they have developed a much more complete understanding of the concept of equilibrium. They were able to recognise that when a body is instantaneously at rest there must be a net force acting on it and hence that it is not in equilibrium. This is illustrated by their

responses to question 1(c), which 58% of the level 3 students answered correctly, and also for position B of question 13 where they had to recognise that the body concerned was not in equilibrium even though it was instantaneously at rest before they could indicate the direction of the force acting correctly.

Their understanding of gravity was also greatly enhanced and their responses to question 13 showed that they could recognise that the force of gravity is always a constant downward force on any body. In particular they knew that this force could act in isolation on a body that is moving upwards.

To summarize the level 3 students had all demonstrated a clear understanding of forces particularly their identification and their effects on motion. This includes a clear understanding of equilibrium, the force of gravity and Newton's first and second laws.

9.5 Conclusions and Implications for Instruction

As students pass through the levels of the hierarchy from level 0 to level 3 they move from a stage where they use almost exclusively the misconception that there must always be a force in the direction of motion to a stage where they have completely overcome this misconception. The intermediate levels 1 and 2 illustrate the students having overcome aspects of their original misconception but reverting to using it in some situations.

This situation is not at all surprising as it reflects the historical development of the laws of motion. Aristotle argued that there must be a force acting in the direction of motion and his thoughts dominated scientific thinking for many hundreds of years before they were questioned and replaced by Newton's laws of

motion. Here we see students on level 0 with ideas very similar to although much less refined than those of Aristotle. Those on levels 1 and 2 have questioned their initial starting point and reached some degree of acceptance of the Newtonian model, but still revert to their force in the direction of motion misconception at times. This happens when they encounter situations in which they have not yet reconciled their intuitive ideas with the Newtonian model. While the level 3 students have accepted completely the Newtonian outlook on motion.

Those students who expect there to be a force in the direction of motion, for example the level 1 students when dealing with forces that act indefinitely, are unable to proceed successfully with the application of Newton's second law and the solution of a mechanics problem. Their difficulties arise because they are unable to identify initially the forces that are acting in a situation. For example when dealing with a projectile they may expect there to be a force in the direction of motion, when there clearly is not one present. Not only does the misconception inhibit their ability to solve problems, but it also contaminates their understanding of other concepts such as gravity. This contamination of course applies to many other aspects of dynamics and is illustrated well by the responses to the level 3 questions.

In order to improve students individual understanding and promote their progression through the levels of the hierarchy they need to overcome this misconception at an early stage. It must be challenged by highlighting the weaknesses of the students own intuitive ideas. Rectification can then take place by providing alternative explanations that the students can see overcome the weaknesses of their original ideas, explaining satisfactorily the situations used to challenge the students intuitive ideas. The distribution of students to levels, shown in Table 104, indicates that only 23% of students have reached level 3

and completely dispelled the force in the direction of motion misconception. Thus it appears that many of the teaching strategies currently in use do not challenge this misconception and therefore are not changing students ideas about the relationship between force and motion. However the new findings of this research, as well as revealing the problems experienced by students, do also show how their understanding develops. Thus it provides a framework, that has not previously existed, in which to develop new teaching strategies.

In teaching, one strategy that would help promote student understanding would be to concentrate on a qualitative approach to mechanics until the students have grasped an understanding of the nature of force before continuing with quantitative problems. A qualitative approach would initially place more emphasis on the identification of forces. This would benefit from being carried out first in a statics environment where there will be no motion to confuse the students. Once students have developed the ability to identify forces they could then proceed to dynamics situations. Here it would be useful to define a force as something that would cause a change in the motion of the body to which it is applied. In particular that when more than one force acts, as is the most usual case, that a non zero resultant force would cause a change in motion. Once students have grasped these conceptual ideas it will be possible for them to progress to the formal application of Newton's laws to the whole of mechanics without such great problems as some students experience at present.

Chapter 10 - A Hierarchical Model of the Development of Student Conceptual Understanding of Momentum

10.1 Introduction

As the research project was progressing the concept of momentum, one of the most fundamental of mechanics, became of increasing interest. The work on the momentum video for SMP and the pre-pilot version that preceded it was one factor that contributed to this interest. The second was the approach taken by SMP in their written materials for the Mathematics 16-19 course. They used momentum to introduce Newton's first and second laws, rather than the more traditional approaches, to be found in many other textbooks. The third was the absence of recent research into student understanding of momentum. The only recent publication that could be traced was that of Lawson and McDermott (1987), that looked at one aspect of momentum, the impulse-momentum equation in one dimension.

Therefore, after the successful analysis of the results from the force survey was completed, momentum was selected as another area suitable for a similar investigation. The approach taken would be similar to that for force with a large scale survey followed by an analysis of results using the methodology adopted for the force survey. The only major difference was that no pilot study would be undertaken, as the force study, already described in chapter 9, had demonstrated the feasibility of using this research method..

Once momentum was selected for study it was necessary to decide upon the areas for investigation. The Exeter College experiment had used one video on

momentum and hence there existed test questions designed to look at the basic ideas of momentum. This would present a very confined area for investigation and so impulse and conservation of momentum were also included.

This chapter describes the implementation of the study, the results obtained and implications of these results for teachers of mechanics.

10.2 Design of the Questionnaire

The first stage of the investigation was to prepare a questionnaire that could be used to explore student understanding of momentum. Several questions had already been prepared for use in the video experiment at Exeter College, covering the basic concept of momentum as the product of mass and velocity, along with the fact that it was a vector quantity. These questions have already been described in section 5.2.7 and are listed in section 6 of appendix C. Most of these questions were used in the survey with the exception of 1(iv) and 3 (numbered as in appendix C).

As well as the questions that had already been developed there was a need for further questions, which concentrated on the relationship between momentum and impulse and the principle of conservation of momentum. Both of these additional areas included situations in one and two dimensions. A few additional questions on the magnitude of momentum and its vector nature were added and one of the original questions extended to include a development on impulse. Table 108 indicates the questions which apply to each of the areas considered in the survey.

Topic Area	Question Numbers
Momentum as product of mass and velocity	1, 3, 6, 7, 9, 14, 19(ii).
Vector nature of momentum	6, 8(i), 16.
Impulse in one dimension	4, 10, 19(i).
Impulse in two dimensions	8(ii), 13, 15(ii).
Conservation of momentum in one dimension	2, 5, 11, 12, 17.
Conservation of momentum in two dimensions	15(i), 18, 20.

Table 108 - Allocation of Questions to Topic Areas for the Momentum Questionnaire

Small scale trials of the questions were undertaken with local sixth-formers before the tests final format was decided. These trials helped to identify poor wording and confusing questions, as well as indicating some of the responses that could be expected. A copy of the final version of the questionnaire is included in section 10 of appendix C.

10.3 Administration of the Survey

In January 1990 a large number of schools were approached and asked if they would be willing to help with the survey. The schools were asked if they could provide students who had studied momentum, impulse and conservation of momentum. The initial response was very good, with many of the schools that had participated in the force survey offering to take part. Initially the schools were asked to return the questionnaires by the end of May, but this deadline was extended to the end of September. A total of 585 questionnaires were returned by this date.

Once the tests had been returned the students responses were categorised and analysed in the same way as the force questions had been. There was a small number of students who had not completed all of the questionnaire and so they were removed from the survey reducing the effective total to 549 students.

10.4.1 The Formation of the Model of Conceptual Development

The process used to form the levels of the hierarchy was the same as that used for the force model described in chapter 9. The methodology described in section 9.2 was applied in exactly the same way. In this section the criteria of section 9.2 are presented with evidence to support the formulation of the levels that constitute the model.

(i) The questions on each level should have similar degrees of difficulty, i.e. the questions on any one level should be answered correctly by a similar proportion of students.

It would not be expected that all the questions on any one level should have exactly the same degree of difficulty, but that they should lie within a range of difficulty. Table 109 shows these ranges. From the table it can be seen that there is no overlapping of the levels and that the ranges for each of the levels are of a similar size, between 21% and 26%. Thus the questions on each level are of similar degrees of difficulty, satisfying criterion (i).

Level	Interval	Range
1	75 - 96%	21%
2	44 - 70%	26%
3	8 - 33%	25%

Table 109 - Correct Response Intervals for Each Level

(ii) Success on each question should be associated with success with the other questions on the level. This association was measured with the phi coefficient for dichotomous data.

Since the phi coefficient was the main tool used for the formation of the groups of questions that identified the levels, there should be little difficulty satisfying this criterion. The phi values for the momentum survey seemed on the whole to be lower than those obtained for the force analysis, but they were similar in that they had greater values for the more difficult questions. Tables 109, 110 and 111 show the phi values between the questions on each level and Figures 57, 58 and 59 illustrate these links.

These tables and figures illustrate that there is a high degree of association between the questions on each level, satisfying criterion (ii).

	1(i)	7(i)	7(ii)	9	14(i)
7(i)	.301	-	-	-	-
7(ii)	.233	.452	-	-	-
9	.217	.109	.167	-	-
14(i)	.210	.241	.189	.115	-
14(ii)	.218	.263	.348	.126	.520

Table 110 - Phi Values for the Level 1 Questions

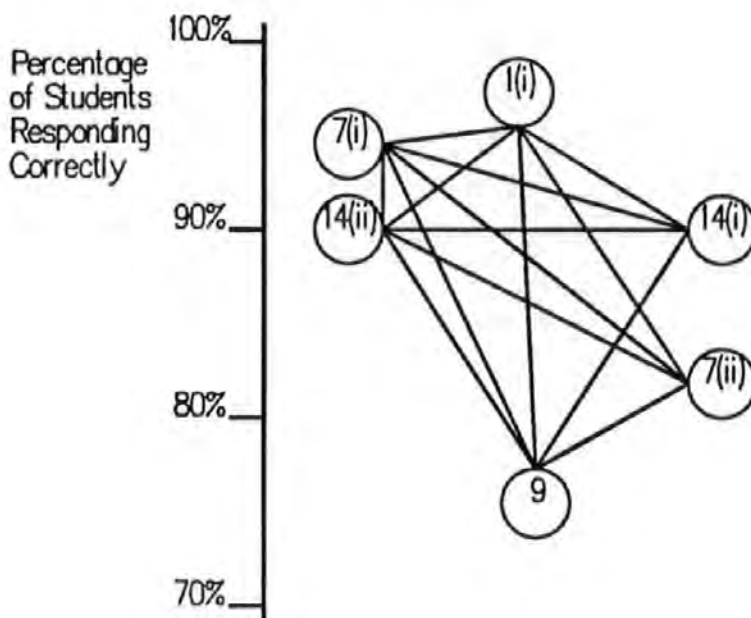


Figure 57 - Phi Links Greater Than 0.100 for the Level 1 Questions

	3	5	8(i)	10	16
5	.338	-	-	-	-
8(i)	.141	.197	-	-	-
10	.343	.395	.256	-	-
16	.249	.293	.411	.271	-
19(i)	.347	.287	.224	.460	.264

Table 111 - Phi Values for the Level 2 Questions

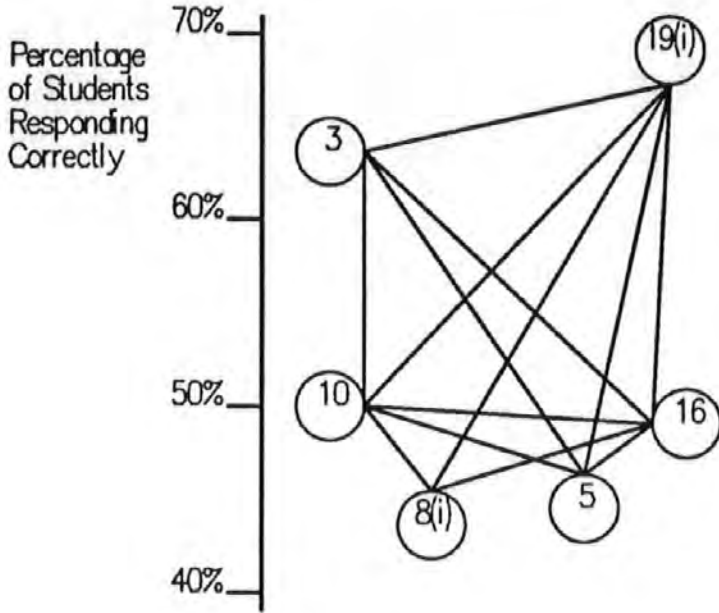


Figure 58 - Phi Links Greater Than 0.200 for the Level 2 Questions

	8(ii)	12	15(i)	15(ii)
12	.223	-	-	-
15(i)	.362	.209	-	-
15(ii)	.298	.212	.367	-
20	.312	.206	.355	.390

Table 112 - Phi Values for Level 3 Questions

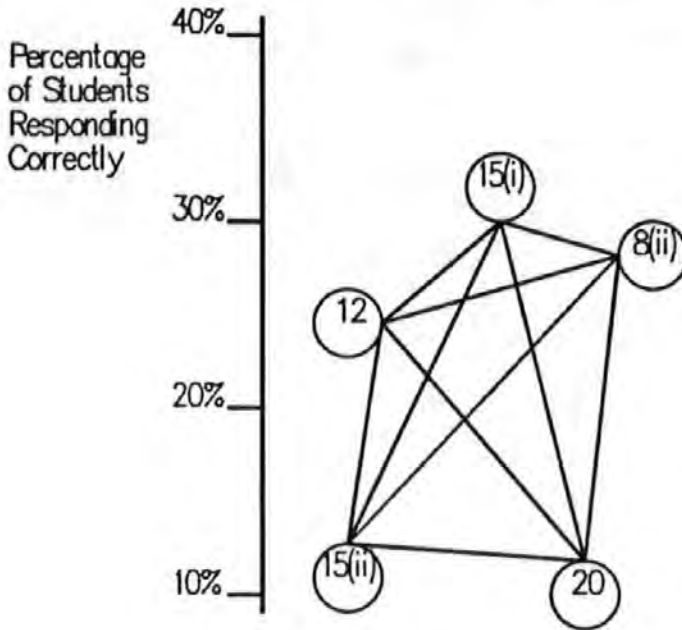


Figure 59 - Phi Values Greater Than 0.200 for the Level 3 Questions

(iii) Students should not reach any level without passing all the lower levels. It would only be acceptable for a very small proportion of the sample to attain a level without being successful on all the lower levels.

The analysis led to the identification of three levels. To succeed on a level the students were required to answer a certain minimum number of questions correctly. This pass mark was defined to be as close as possible to, but not exceeding 70%. The students were assigned to the highest level that they passed, or if they did not pass any, to level 0. Table 113 shows the distribution of students to levels and the pass mark for each level.

Level	Percentage of Students	Pass Mark
0	6%	
1	42%	4/6 (=67%)
2	38%	4/6 (=67%)
3	14%	3/5 (=60%)

Table 113 - Distribution of Students to Levels and Pass Marks

There were a few students who did not conform to the model and passed a level without passing all the lower levels. The proportion of students doing this was very small, only 3% of the whole sample. Thus criterion (iii) is satisfied.

(iv) There should be a good degree of sense to the levels from a mechanics viewpoint. The abilities of the students reaching each of the levels are summarised below.

Level 1

To achieve an understanding at level 1 the students should be able to;

- (i) recognise the importance of the product of mass and speed,
- (ii) compare the momentum of different objects, moving in the same direction.

Level 2

To achieve an understanding at level 2 the students should be able to;

- (i) cope with simple situations where the mass of a moving body changes,
- (ii) recognise that momentum is a vector quantity,
- (iii) recognise that momentum is the product of mass and velocity,
- (iv) understand and apply the principle of conservation of momentum, when motion is restricted to one direction,
- (v) understand and apply the impulse-momentum equation, when motion is restricted to one direction.

Level 3

To achieve an understanding at level 3 the students should be able to;

- (i) understand and apply the principle of conservation in 2 dimensions,
- (ii) understand and apply the impulse-momentum equation in 2 dimensions.

This summary shows that there is a meaningful development through the levels of the hierarchy, satisfying criterion (iv). Sections 10.4.2, 10.4.4 and 10.4.6 that follow describe each of the levels in detail. These sections also illustrate that there is a meaningful progression in development of the students understanding from a mechanics viewpoint.

Thus since all four of the criteria are satisfied the model that is now described can be considered to give a valid description of the development of students conceptual understanding of momentum.

10.4.2 Description of Level 0

The students on level 0 form a very small part of the sample, only 6% of the total. Their understanding of momentum and when it is relevant is very weak and generally appears to be nonexistent or very confused. In this section their responses to the questions forming level 1 are examined and suggest the type of reasoning that they use. This enables the level 0 students to be classified into two categories, either confused or speed dominant.

When responding to question 1(i) 55% of the level 0 students responded correctly, compared with at least 97% of the students on the other levels. Here as the balls were at rest there was little opportunity for the speed dominant approach to emerge, however there was considerable evidence of a confused approach among the level 0 students. Of these 16% stated that the ball A (the

higher of the two) had more momentum. This suggests that they are not clear in their own minds as to what momentum is and are looking for any difference between the two balls, for example the difference in their heights. Another 26% gave responses that did not identify either ball. Here again the students appear to have such poor ideas about momentum that they are unable to reach a conclusion.

Questions 7(i), 9 and 14(i) all required the students to identify the object which had the greater momentum. The level 0 students responses to these questions are summarised in Table 114.

Question Number	7(i)	9	14(i)
Correct response	45%	16%	45%
Faster moving object selected	48%	35%	45%
Other / no response	6%	48%	10%

Table 114 - Summary of the Responses of the Level 0 students to Questions 7(i), 9 and 14(i)

In all three of these questions there is large proportion of the students selecting the faster moving object, particularly in questions 7(i) and 14(i) where the students have to select one of either two of three options. For question 9 they are simply asked to compare the momentum of two objects and this allowed more scope for the other responses that appeared. In these cases the two incorrect approaches taken by the level 0 students are evident, some using the speed dominated approach and others simply being confused.

It could be argued that the students select the faster object because this has the greater kinetic energy rather than because it is simply faster, although this approach is still incorrect. Some students clearly do reason in this way, but it is only a very small proportion of these students. This does become clear from the

students responses to parts (ii) of questions 7 and 14 where the students are asked why they gave the response in part (i). Their responses to these are summarised in Table 115.

Question	7(ii)	14(ii)
Greater momentum	13%	26%
Greater kinetic energy	6%	6%
The fastest one	-	16%
Other responses	61%	32%
No response	20%	19%

Table 115 - Summary of the Level 0 Students Responses to Questions 7(ii) and 14(ii)

The table does illustrate that there is only a small proportion using the kinetic energy argument. It does also indicate the extent to which students consciously select the faster moving one in question 14(ii), where this response was recorded.

Table 115 provides further evidence of the confused approach existent among the level 0 students. For both questions significant proportions of the students fail to give any justification for their responses or give vague responses that cannot easily be classified. In spite of the fact that some of them may have given correct responses to part (i) of the question many are unable to clearly justify their response.

To conclude the small proportion of students who are on level 0 have either a very confused view of momentum or seem to take a speed dominated approach, which ignores the mass of the object under consideration. As well as these difficulties the level 0 students also share the problems encountered by the level 1 and level 2 students.

10.4.3 Questions Forming Level 1

1. Two identical balls are dropped from different heights at exactly the same time and allowed to fall. A is released from a height of 15 m and B from a height of 10 m. How does the momentum of the two balls compare;

(i) at the instant they are released?

7. (i) Which would be more difficult to stop a small lorry of mass 3 tonnes travelling at 20 mph or a car of mass 1 tonne travelling at 50 mph ?

(ii) Why ?

9. Two balls of mass 8g and 16 g are fired along a straight track at different speeds. The diagram shows the position of the balls after two seconds. How does the momentum of the two balls compare ?



Figure 60 - Diagram for Question 9

13. (i) Which of the following is most likely to break a window ?

A - A 500g ball moving at 2m/s.

B - A 300g ball moving at 4m/s.

C - A 100g ball moving at 9m/s.

(ii) Why did you chose this one ?

10.4.4 Description of Level 1

Level 1 contains the greatest proportion of the students, comprising 42% of the sample. The students on this level have overcome the basic problems exhibited by the level 0 students. This is illustrated, for example by their responses to questions 7 and 11, where the vast majority of the students gave acceptable responses and were able to justify them. The results of these questions are summarised along with the other level 1 questions in Table 116.

Question	Correct Response	Correct Justification
1(i)	97%	-
7	97%	86%
9	67%	-
14	96%	95%

Table 116 - Summary of the Level 1 Students' Responses to the Level 1 Questions

So the level 1 students have reached the stage where they have acquired an understanding of the fundamental concept of momentum, but are unable to appreciate all the properties of this quantity. An examination of the responses of the level 1 students to the level 2 questions identified where the level 1 students' understanding of momentum begins to break down.

In spite of the fact that these students understand that momentum is proportional to the mass of an object, their understanding of mass itself is open to question as illustrated by their responses to question 3. Here they had to recognise that the mass of an object is decreasing at the same rate as its speed is increasing, so that the momentum would remain constant. Of the level 1 students in the sample 41% responded correctly, but 24% said that the value of g would be decreasing and implied that they felt that mass depended on g . This group of students

clearly confused the concepts of mass and weight (or force of gravity). A further 35% of the sample failed to respond or gave other responses, which indicated that they did not appreciate that the mass of an object could change.

Questions 8(i) and 16 had been included in the survey to test if students understood the vector nature of momentum and formed part of level 2. For both these questions the level 1 students did not treat momentum as a vector quantity. Their responses are summarised in Table 117.

Question number	8(i)	16
Treated momentum as a vector	21%	24%
Treated momentum as a scalar	72%	45%
Other / no response	7%	31%

Table 117 - Summary of the Level 1 Students Responses to Questions 8(i) and 16

Here a small proportion of the students recognised that momentum was a vector, but the majority in both cases treated it purely as a scalar quantity. They stated that the magnitude did not change, remaining constant. Thus they did not in any way acknowledge that momentum is a vector quantity. The other responses given for question 16 included some that referred to increases or decreases of the momentum. These responses are very similar to those described in section 8.2.1, which dealt with students intuitive understanding of velocity. These students seem to be aware that the momentum should change but are unable to describe this change.

Two other questions, 15 and 18(i), aimed to test whether students understood the impulse-momentum equation. In both questions forces of identical magnitudes were applied to objects of different masses and the students asked about the

resulting momentum of the objects. The level 1 students responses to these questions are summarised in Table 118.

Question number	15	18(i)
Same momentum	18%	52%
Heavy one more momentum	50%	28%
Light one more momentum	15%	10%
Other / no response	17%	9%

Table 118 - Summary of the Level 1 Students Responses to Questions 15 and 18(i)

Many of the students did not understand how the resulting momentum was related to the product of force and time. Due to this lack of understanding they resort to other arguments that they can associate with momentum. The most predominant of these is to ignore the unknown velocity and to concentrate on the masses of the objects, thus they argue that the object with the greater mass will have the greater momentum. Other students argue that the lighter object will have a greater momentum. Presumably these students expect the lighter mass to have a velocity with a greater magnitude, but do not realise that this will give the same momentum. They have moved towards a correct understanding of the situation but have not reached a complete realization of the impulse-momentum equation.

The final area in which the level 1 students experienced difficulties was with the principle of conservation of momentum in collisions. Question 5 required the students to apply the principle of conservation of momentum in a situation where one object was initially stationary and a perfectly elastic collision took place along a straight line. Here it was possible to obtain without considering the direction of motion, solely the magnitude of the velocities. The students responses to this question are summarised in Table 119.

Both objects move with smaller velocity	16%
Both objects move with same velocity	17%
Both objects move (no mention of velocity)	47%
Other / no response	20%

Table 119 - Summary of Level 1 Students Responses to Question 7

As the Table 119 indicates the majority of students were able to predict correctly that both objects would move together after the collision. However very few were able to make predictions about the magnitude of velocity after the collision. The majority of the students did not make a prediction while several stated that the magnitude of the final velocity would be the same as the initial velocity. Both these and most of the other responses show how the students have failed to actually use the principle of conservation of momentum.

In conclusion it seems that the level 1 students have assimilated the fundamental ideas of momentum, recognising situations where it is relevant and how to calculate it, but do not appreciate that it is a vector quantity. Also they find situations where the mass is changing difficult to cope with. They are however unaware of the relationship between momentum and impulse or the principle of conservation of momentum. As well as these problems the level 1 students also share those difficulties experienced by the level 2 students.

10.4.5 Questions Forming Level 2

3. During a certain stage of its flight the magnitude of the momentum of a rocket remains constant even though its speed is increasing. Explain why this situation could arise.

5. An astronaut floating deep in space catches a ball that has been thrown to him. Describe as fully as possible what would you expect to happen to him ?

8. A puck of mass 1kg is moving with speed 1.8 m/s when it hits a barrier, as shown in the diagram. It rebounds still moving at the same speed. How does the momentum of the puck before the collision compare with the momentum after the collision ?

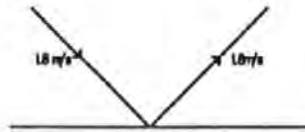


Figure 61 - Diagram for Question 8

10. Two pucks, that are initially at rest, have different masses, one being much greater than the other. If they are subjected to the same constant force for five seconds, how will the momentum of the two pucks compare when the force is removed ?

16. A skater follows a curved path, moving at constant speed. What happens to the skaters momentum ?

19. Two people on roller skates are standing facing each other. One pushes hard against the other and they move apart. If one person is much heavier than the other how does;

(a) the momentum of each skater compare ?

10.4.6 Description of Level 2

The level 2 students formed 38% of the sample and the majority had overcome all the problems exhibited by the level 1 students. The recognising of momentum as a vector still caused problems for a few of the students on this level and most of their problems that are described below are concerned with the use of momentum vectors. Table 120 illustrates how the level 2 students have mastered the problems that the level 1 students encountered with the level 2 questions.

Question	Percentage Correct
3	88%
5	71%
8(i)	67%
10	81%
16	75%
18(i)	97%

Table 120 - Percentages of Level 2 Students Responding Correctly to the Level 2 Questions

Thus we can see that the level 2 students recognise momentum as a vector quantity and can use both the principle of conservation of momentum and the impulse-momentum equation in simple cases where the motion is restricted to a straight line. Their understanding appears to breakdown when these ideas are extended to two dimensions or cases where the direction of motion changes.

All the level 3 questions involve the application of the principle of conservation of momentum or the momentum-impulse equation in situations where the direction of motion changes and it is here that the level 2 students encounter difficulties. Examining the level 2 students responses to the level 3 questions illustrates these difficulties.

Questions 12, 15(i) and 20 that involved the principle of conservation of momentum will be considered first. When answering question 12, only 25% of the level 2 students gave acceptable responses. Two different arguments were used by the students to obtain incorrect responses, in addition to those that were difficult to classify. The first of these used by 46% of the level 2 students was to state that the final velocity would be less than the original. In giving this response the students had not taken account of the fact that the smaller puck was moving backwards in the opposite direction to the larger puck, their answers based on the magnitude of the momentum and not taking account of the direction. The second approach yielded the response that the momentum was the same and this was supported by statements about momentum being conserved in collisions. This approach was used by a smaller number of students, 6% of the level 2 students.

Questions 15(i) and 20 concerned collisions in two dimensions and required the students to use vectors to obtain their responses. Both questions were similar but 20 involved objects of different masses. Three main approaches to these problems were identified as well as others that could not be classified. The first of these is a correct manipulation based on the addition of the two momentum vectors concerned. Figure 62(i) illustrates this type of response. The second is very similar to the first but ignores the different masses, so that this does not apply to question 15(i). The third approach is a vague arrow added to the diagram without any evidence to support its construction, but pointing in approximately the correct direction. The length of these arrows generally did not seem to be of any significance. A typical response of this type is shown in figure 62(ii).

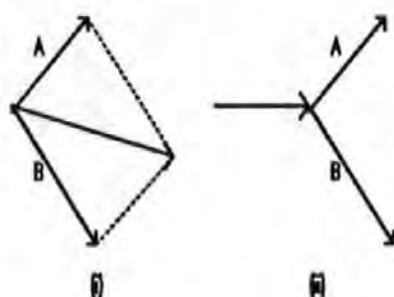


Figure 62 - (i) A Correct Response (ii) A Vague Response

The percentages of each student giving each of these types of responses are recorded in Table 121.

Question number	15(i)	20
Correct Response	32%	2%
Mass Ignored Response	-	38%
Unsupported Vague Response	44%	30%
Other / No Response	24%	30%

Table 121 - Summary of the Responses of the Level 2 Students to Questions 15(i) and 20

The results suggest that a high proportion of the students use very imprecise intuitive ideas to find the initial velocity, with some others having little or no idea how to proceed with the problem. There are also some students who are able to take a correct approach but they tended to overlook the different masses involved in question 20.

The other two level 3 questions were 8(ii) and 15(ii), which were concerned with the impulse-momentum equation in two dimensions. The responses given by the

level 2 students to question 15(ii) were very poor and exhibited little evidence of any consistent reasoning. Many of their responses were complicated by incorrect responses to part (i). However question 8(ii) identified one incorrect approach as well as the correct one and an assortment of other inconsistent ideas. For this question 31% of the level 2 students were able to draw correct vector constructions of the situation to find the impulse. The main incorrect approach was to draw an arrow in approximately the correct direction but of a length that could not represent, even approximately, the correct magnitude. This approach was taken by 42% of these students.

To summarise, the level 2 students have demonstrated an understanding of the impulse-momentum equation and the principle of conservation of momentum, when they are restricted to motion in one direction, and recognise that momentum is a vector quantity. However they are unable to extend these ideas to situations where there is a change to the direction of motion. Their main problem stems from their inability to cope with or recognise the vector manipulations required to solve these problems and have to resort to using imprecise intuitive ideas, that often lead to very vague responses.

10.4.7 Questions Forming Level 3

8. A puck of mass 1 kg is moving with speed 1.8 m/s when it hits a barrier, as shown in the diagram. It rebounds still moving at the same speed. On the diagram, using the same scale, draw a vector to represent the impulse that acts on the puck.

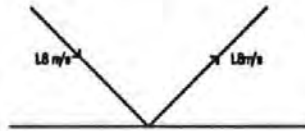


Figure 63 - Diagram for Question 8

12. When a small train moving on a track collides with a heavier stationary one the small train moves backwards and the heavy one forwards. How does the momentum of the heavy train compare with the initial momentum of the light one.

15. A moving puck, A, of mass 1kg collides with a stationary puck, B, of the same mass. The diagram below shows the velocity vectors of the two pucks after the collision.

(i) Draw and label a vector to represent the initial momentum of the puck that was moving before the collision, showing how you obtain it.

(ii) Also draw and label a vector to represent the impulse that is exerted on the moving puck during the collision

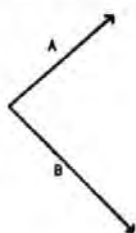


Figure 64 - Diagram for Question 15

20. Two pucks, A and B, have masses of 1kg and 2kg respectively. Initially mass A is moving towards B which is stationary. The vectors in the diagram show the velocities of A and B after the collision. Draw vector to represent the initial velocity of A, showing how you obtain it.

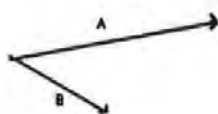


Figure 65 - Diagram for Question 20

10.4.8 Description of Level 3

The level 3 students compose only 14% of the whole sample, which is a relatively small proportion. These students have demonstrated a good understanding of the aspects of momentum covered in the survey. Table 122 shows the percentage of level 3 students who gave correct responses to the level 3 questions.

Question Number	Percentage of Students
8(ii)	87%
12	73%
15(i)	96%
15(ii)	57%
20	48%

Table 122 - The Percentages of Level 3 Students Giving Correct Responses to the Level 3 Questions

Table 122 shows a considerably higher level of achievement than for the level 2 students, but for questions 15(ii) and 20 the number of students responding correctly is much lower than for the others. The majority of the level 3 students correctly identified the impulse vector for question 15(ii), but it was one of the questions that even some of the level 3 students found difficult. For question 20 46% of the level 3 students drew diagrams that assumed that both the pucks had the same masses. Here the problem lies not with the drawing but with noting that the different masses are significant.

Thus the level 3 students have demonstrated a good understanding of the nature of momentum as well as the momentum-impulse equation and the principle of conservation of momentum in two dimensions. These students seem to have completely consolidated the concept area of momentum.

10.5 Conclusions and Implications for Instruction

As a student's understanding of momentum progresses it passes from being very confused or intuitive at level 0 to very comprehensive at level 3. In between these two extremes there are two areas of development, which progress initially to a scalar understanding and then to a vector understanding.

The first of these two areas is the fundamental concept of momentum itself as the product of mass and velocity. This is first grasped in a scalar sense at level 1 where the students regard momentum as the product of mass and speed. They are able to deal with situations where the direction of the momentum vector is not important, but are unable to identify differences in momentum due to direction until they reach level 2. They grasp the idea in a scalar sense at one level and in a vector sense at the next level.

The second of the areas of development concerns the understanding of the momentum-impulse equation and the principle of conservation of momentum. The students first demonstrate an understanding of these ideas at level 2. Here their understanding is very much limited to cases where the motion is restricted to one direction and does not even extend to cases where there is motion in two directions along the same straight line. The students are using momentum as if it were a scalar quantity, i.e. the product of mass and speed. So although the students realise that momentum is a vector they do not treat it as such when using the principle of conservation of momentum or applying the momentum-impulse equation. However on level 3 the students are able to deal with cases where the principle of conservation of momentum and the impulse momentum equation need to be applied in two dimensions. Again in this area we see the students developing a scalar understanding at one level and a complete vector understanding at the next level.

Since the development of a vector understanding seems to be preceded by a scalar understanding it could be argued that instruction should be based on a scalar treatment of the topic, where motion is restricted to one direction followed by an extension into two dimensions with vectors. Against this can be set the fact that the students are clearly not good at dealing with vectors and so should be introduced to them at the earliest possible stage, so that they can become more familiar with vectors.

The fact that students are not used to using or dealing with vectors became clear from several of the responses to the questions, for example question 15(i), where a simple vector addition was required, but only produced by 10% of the students. Also on questions where it was possible to give a reasonable response without referring to the direction of the momentum the students tended to do this. On question 6 only 9% of the students referred to the direction of the momentum. In question 19(i) there was another opportunity that very few students took to demonstrate their understanding of momentum as a vector quantity.

There are two possible reasons for this poor ability of the students to cope with the vector aspects of momentum. The first is that this is an area of considerable difficulty to the students and that they need much more help in grasping an understanding of it. The second is that some text books place too much emphasis on the one dimensional properties of momentum and provide only a later extension into two dimensions. Such an approach is taken by, for example, Bostock and Chandler (1975), who use five examples when introducing momentum, with only the last one considering two dimensional motion. Other similar examples can be found in other textbooks. In contrast however the new SMP materials treat momentum as a vector from the very outset, placing more emphasis on this aspect of it than many other texts.

Here we have for the first time the identification of the problems that students encounter with momentum and a model of the development of their understanding of this concept. This model shows the problems that the vast majority of students have with treating momentum as a vector, with almost half the students not recognising momentum as a vector quantity. Efforts to improve this could be based either on developing one dimensional ideas and extending into two or by always treating momentum as a vector and not initially restricting motion to one dimension. Whichever approach is adopted there is a real need for more emphasis on vector methods at some stage. In particular more geometrical, rather than algebraic, work may lead an improved understanding of the vector properties of momentum.

Chapter 11 - Implications of the Research

11.1 Introduction

Earlier chapters have presented detailed results of the research and their individual implications for teachers, the development of new resources and further research. This chapter draws together the common elements of the research into student understanding and how this relates to the work on video. In particular it raises questions that arise as a consequence of the research, that themselves could become the subjects of further studies.

11.2 Misconceptions

The major feature of all the work on student understanding has been the presence of student misconceptions. The results of chapter 8 have shown the extent of this problem at the outset of mechanics courses, while chapter 9 has shown how one misconception dominates students' whole understanding of the concept of force. Whilst the work described here has identified the presence of these problems and shown how they inhibit the development of student understanding it has not examined why these misconceptions are formed or how they can be broken down. There is a potential for further research to establish how these misconceptions are formed so that preventive measures can be taken at an early stage. One possible area of investigation is regarding the teaching that takes place during the primary years where there may be many teachers who themselves have the misconceptions and who need to have help before they can really begin to teach about mechanics concepts, even in a simple way at a very low level. There is of course also a need for research to establish the best methods for remedying the problems caused by these misconceptions.

Two factors that have emerged about misconceptions are firstly that they are generally very similar and secondly they are held in a very individual way by the students. This means that while teachers will be dealing with the same problem they may need a wide variety of approaches available to enable them to help different students. For example consider the problem concerning the time taken for balls of different masses to fall to the ground from the same height. Some students may be easily able to correct their viewpoint if the teacher explains that the force of gravity always causes the same acceleration. Other students with more deeply embedded misconceptions may need to carry out some simple experiments to rectify their misconception. It is in this area that there is a potential for the use of both video and interactive video.

The results of the video work have indicated that the best use of video is for conveying conceptual ideas, using visual illustrations and real examples. If video design could include considering how to challenge misconceptions as well as teaching about the concept it could greatly assist teachers in overcoming the misconceptions problem. Again the results of any future work into the best approaches for dealing with misconceptions would be of much value in this area.

While video could play a part in dealing with misconceptions, interactive video could be an even more powerful tool for both identifying and rectifying misconceptions. Due to its ability to provide a course of instruction tailored to an individual student it could first use probing questions to establish the state of the students understanding and then take the student through a series of remedial steps. As an interactive system reacts to each response given by the student it can determine whether the student is progressively changing his viewpoint or if an alternative approach is needed. Also it can react to any peculiarities that a particular student may have. Finally the video can present a number of problems to the student in order to confirm that the misconceptions have been abandoned and replaced with a sound framework.

Although interactive video is still of limited availability, there have been an increasing number of projects that have put these systems into schools, and any resources developed for rectifying misconceptions would add further weight to the argument for providing these facilities.

11.3 Hierarchies and Order of Teaching

The two chapters that described the models formulated for the development of students understanding, have presented the results of a major new view of this area, by concentrating on development rather than identifying problems. This new approach has revealed that the two areas considered, both contained one common feature. This was that those aspects of the topic that required the use of vectors were to be found only on the higher levels of the hierarchy. This raises an important question, whether the teaching should follow the stages outlined in the model or whether an alternative approach to the teaching would lead to a different model of student understanding. Traditionally concepts have often been introduced without, or even taught completely without the use of vectors. It may be because of this teaching approach that students encounter the difficulties that they find with concepts that require the use of vectors, and that an approach that uses vectors as an integral part of the teaching programme, could produce a different set of hierarchies.

There are two ways in which further research could address this problem. The first is by a study of why the students understanding develops in this way. The work of chapters 9 and 10 has used empirical methods to establish the models, but this has not given reasons why the models take the form that they have. It may be that there is a natural development or that other factors such as the teaching approaches that they encounter or their real life experiences have more influence on their understanding. If these reasons were known it would be possible to determine whether an alternative approach to teaching would be more successful.

The second possible approach would be research based on a comparison of the development of the understanding of students taught in two different ways. A group taught using traditional methods could be compared with a group using an approach based on a fully integrated vector approach. A comparison of this nature could determine whether the model would be influenced by the type of teaching that has been used or if an alternative approach has the potential to lead to improved understanding.

With such an alternative approach there is again a potential for the use of video in the teaching of mechanics. It has become clear that where video can be an effective medium is for conveying ideas and concepts that can be illustrated visually. Vectors lend themselves to the sort of demonstrations that can be superbly produced on video and using overlay techniques related to real situations.

The research described here has dealt with only two specific areas of mechanics and there are several other areas within mechanics that could be investigated in the same way. If further similar investigations were carried out in this way then there would exist a firm foundation on which new resources for the teaching of the whole of mechanics could be developed. As the results of empirical studies of this nature become available then there would be a need, as described above, to determine whether the models that were developed were as a result of the students characteristics or as a result of the teaching that they had received. Also as more concept areas are investigated in this way, there would be a considerable opportunity to make comparisons of the way in which student understanding develops in different topic areas.

11.4 Mechanics and Physics

In many sixth form colleges and schools it has been traditional for there to be very few links between the mathematics and physics departments, yet the mechanics elements of many A-level mathematics courses share much common ground with physics. It is clear from the results of the video experiment described in chapter 7 that the physics teaching has had some affect on the understanding of the students. Certainly the affect of the physics teaching on the students involved in the experiment was more significant than was anticipated at the outset of the experiment. This raises a number of questions about the relationship of the work of the mathematics and physics teachers and the way in which the video experiment was undertaken.

First considering the relationship between the mathematics and physics departments. There is no doubt that there are differences in the way that students who have and have not studied physics at A-level learn mechanics as part of their mathematics courses. The research here has merely unearthed evidence of this difference, but has not addressed why it exists or the extent of the differences. These are questions that can only be answered by further research. But the fact these differences do exist raises questions about the way that mechanics is taught, both in mathematics and in physics. The current trend seems to be for both departments to ignore what the other is doing and even to use different approaches to the same topic. However there is considerable scope for liaison between the two departments, even to the extent of producing a joint teaching scheme. Alternatively there may be a need to treat differently those students taking mathematics, who are not following A-level physics courses. Certainly all these possibilities would involve the expenditure of considerable teacher time and raise logistic problems in schools. While it may be appropriate for teachers to pay more attention to the affect of physics teaching on their students, it is probably important that further research is undertaken in this specific area before too much action is initiated in schools.

The other problem raised concerned the affect of the physics teaching on the result of the experiment. It seems that the long term nature of the experiment has allowed the physics teaching to have a greater affect than was originally anticipated on the learning of the students. In retrospect it may have been more appropriate to conduct a number of shorter term experiments and to have monitored the activity of the physics teachers both before and during the experiment. The monitoring before to ensure that the topic had not been extensively covered by the physics teachers and during to ensure that there was no other source of teaching relevant to the topic under consideration.

11.5 Video and Mechanics Teaching

There have already been a number of references to the use of video and interactive-video in the teaching of mechanics. As the research has progressed the inadequacy of many of the existing video resources to meet the needs of current students has become more apparent. The research has also revealed that the best use of video is for communicating concepts that can be displayed visually. There are many areas in mechanics where this forms an important aspect of the teaching, especially when it is used alongside real examples.

The research into student understanding has clearly shown that many of the problems that the students encounter with mechanics are of a conceptual nature. They often find it difficult to explain or visualise a system and even harder to predict the effect of an action on a system. These are just the sort of ideas that lend themselves to a treatment by video. Those videos that have been well received by the students involved in the experiment are those that have taken this type of approach.

Modern video production needs to address the conceptual needs of the students. It is in this area that it has the potential to fulfil students needs and make a valid contribution. Many of the existing video resources fail to take this approach and so are of little or of limited value. Many of the OU productions, which form the bulk of the available resources, are particularly weak in this respect. So there is a need for a whole range of video resources designed to use the potential of video to communicate conceptual ideas to deal with the conceptual elements of mechanics. In the production of these videos the model described in chapter 6 would form a framework for these resources. It would also be important that these videos were produced with a uniform approach, so that there were no inconsistencies between the different videos. Ideally these videos would be produced by a single team that could ensure that they then carefully covered the whole of mechanics with a consistent approach.

While video appears to have the potential to take a part in mechanics teaching, there are many other new ideas that can also contribute to improved student understanding. These include practical work, problem solving and the use of concept questions. It as an integrated part of a scheme of work, alongside these new ideas and also traditional teaching that video has its place.

Appendix A - The Video Review

This appendix contains the latest version of "A Review of the Video Resources Available for the Teaching of Mechanics at A-Level". Note that the page numbers given in on the contents page here refer to the pages in this thesis and not those in the original document.

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Foreword

This review aims to look at all the video material that is readily available for use in the teaching of mechanics. The Open University programmes are all in current use, and can be recorded off air by establishments with a licence. The "Visualizing Mechanics" package is available from the Open University, complete with the accompanying booklet. Details of how to obtain the materials reviewed are also provided.

The descriptions given here, outline the programmes so that teachers can quickly gain an idea of the suitability of the materials for their classes. The tables are also intended to help in this way. The coding used identifies each tape or programme as being completely or partly relevant to a particular course, but should not be taken as a definitive guide. Some programmes will only contain small elements that are not associated with a particular course. The descriptions will provide more information.

A large proportion of the available film that covers topics in mechanics appears very dated and is very slow moving. All these films are listed in the British National Film and Video Catalogue but are not generally suitable for use in the modern classroom. However there do exist some that explain concepts very well and would be valuable in mechanics classes. The films that are listed here, include some more recent productions, are all suitable for use with sixth formers and educationally very worthwhile.

Each film or video has been given a star rating which reflects its suitability for use with sixth formers.

The ratings are explained below.

* Not recommended.

** A better alternative exists.

*** Recommended.

**** Strongly recommended.

In addition each review concludes with a recommendation for the use of that particular video or film, that gives reasons for the rating that has been assigned to that video.

This review has been compiled as part of a research project at the Centre for Teaching Mechanics at Plymouth, Polytechnic South West.

Introduction

Video has an obvious potential for use in the teaching of mechanics. A subject that concerns itself with the study of motion and its causes should be able to make excellent use of a medium that can reproduce these motions as required. It would be expected that mechanics is a subject that has been brought alive by exciting video resources.

Unfortunately however mechanics has gained itself a reputation as being a dull, difficult and often irrelevant subject. This has arisen because so much of mechanics has become lost in calculus and algebraic manipulation. Many mechanics textbooks seem to have lost sight of the real world, using unrealistic examples, full of light inextensible strings and frictionless pulleys. Students as a result fail to associate mechanics with the real world but consider it to be an abstract subject.

Additionally another difficulty has come to light with mechanics and has been the subject of much research [1]. Misconceptions or alternative conceptions are ideas that students have developed about mechanics for themselves, but that are fundamentally incorrect. These misconceptions develop from the students experiences of life and the world around them. They are consequently very deep rooted and difficult to displace. For example many students would be convinced that as one moving object overtakes another both have the same velocity at the instant they are level with each other [2]. Many researchers have come to the conclusion that these misconceptions need to be challenged directly if students are to change their ways of thinking.

The teaching of mechanics, to overcome these problems, needs to address this problem of misconceptions and to make the subject more relevant and interesting for its students. Video can help in this process.

Video, by bringing real life examples of mechanics into the classroom, can provide a real reason for studying the subject. By comparing a traditional approach to the teaching of a concept, with one that utilises video it is possible to see how video can improve student motivation. For example when beginning a study of circular motion it is far more motivating to use a video of a fairground ride as a starting point than to consider a particle P describing a circle ! Discussion of the modelling process will allow students to see how the mathematical model is developed from the real situation, instead of just being produced out of nowhere. Bringing reality into the classroom has two benefits, letting the students visualise more easily what a concept is and when it applies, and also because once a concept becomes more relevant students become more motivated.

In addition to using video as a source of examples from which theory can be developed it is also possible to use video to provide a physical interpretation of mathematical concepts.

Video can also help with the misconceptions problem. One example of a misconception concerns the path of an object that is describing a circular path when the constraining force is removed. Research [3] has shown that almost 50% of students cannot respond correctly. A video such as "Acceleration at Constant Speed" clearly shows what does happen when the constraining force is removed. This type of video, that clearly demonstrates what does happen, can be a great asset when challenging misconceptions that would not otherwise be available in the classroom situation.

Realistic data can be brought into the classroom by video as the process of collecting it is illustrated, or actually taken from the screen by the students. Some of the video material planned for the new SMP Mathematics 16-19 course has been specifically designed to allow students to collect data as the video progresses. In other cases data from situations on the video can be reproduced separately for follow up activities. This technique has not been used extensively but does have a lot of potential, especially if interactive video systems become widely available in schools.

Although much research has pointed to the problems associated with the teaching of mechanics, only a few studies have concerned themselves with evaluating ways of improving the situation. Hake [4] at Indiana University in the U.S.A. has taught students using a new approach. As a result of this the students understanding of mechanics concepts has been better than students taught conventionally in a similar university. The important features of Hake's course were practical work, problem solving activities and considerable use of video.

Although video appears to have a lot to offer, it has remained an under-used medium in mechanics classes. Perhaps one of the reasons for this is that very little video has been produced specifically for sixth form students. However there are existing materials that can be adapted for use by sixth formers as demonstrated by the "Visualizing Mechanics" package. Alternatively it is more likely that many teachers are unaware of the resources that are available, and unsure where to obtain them. It is hoped that this booklet will help by providing a list of the resources that are suitable for use with sixth formers and details of them so that teachers can be guided in their choice of resources.

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Key To Examination Boards

AEB	Associated Examining Board
M	Mathematics (Advanced) (648)
AP	Applied Mathematics (Advanced) (602)
A&S/P	Pure and Applied Mathematics (Advanced) (636) or Applied Mathematics and Statistics (Advanced) (649)
AS	Mathematics (Calculus and Particle Dynamics) (Advanced Supplementary) (995)
CAM	University Of Cambridge
M(C)	Mathematics (Advanced) (Syllabus C) (9205)
F.M.	Further Mathematics (Advanced) (Syllabus C) (9225)
JMB	Joint Matriculation Board
ASP&M	Mathematics (Advanced Supplementary)(Pure Mathematics with Mechanics)
P&M	Mathematics (Advanced) (Pure Mathematics With Mechanics)
P&A	Mathematics (Advanced) (Pure And Applied Mathematics)
F.M.	Further Mathematics (Advanced) (Both Syllabuses)
LON	University Of London
M(B)	Mathematics (Advanced) (Syllabus B) (371)
AP.M.	Applied Mathematics (Advanced) (425)
F.M.	Further Mathematics (Syllabus B) (372)
MEI	Mathematics In Education And Industry Schools Project
M	Mathematics (Advanced)
F.M.	Further Mathematics (Advanced)
OXF	University Of Oxford
P&A	Mathematics - Pure And Applied (Advanced) (9850/4)
P&M	Mathematics - Pure With Mechanics (Advanced) (9850/2)
F.M.	Further Mathematics (Advanced) (9851)
O&C	Oxford And Cambridge
AS	Mathematics (Advanced Supplementary) (8480)
M	Mathematics (Advanced) (9650)
F.M.	Further Mathematics (Advanced) (9651)
SMP	School Mathematics Project
M	Mathematics (Advanced)
SUJB	Southern Universities Joint Board
AS	Mathematics (Advanced Supplementary) (8480)
AP	Applied Mathematics (Advanced) (9218)
P&A	Mathematics (Advanced) (9203)
WJEC	Welsh Joint Examinations Council
M(M)	Mathematics (Mechanics Option)
AP	Applied Mathematics

	M	M	M	M	M	M	M	S	S	S	S	T	T	T	T
	1	S	S	S	S	S	S	1	2	2	2	2	2	2	2
	0	T	T	T	T	T	T	0	7	7	7	3	3	3	8
	1	2	2	2	2	2	2	1	1	1	1	2	2	2	1
	/	0	0	0	0	0	0	/	/	/	/	/	/	/	/
	2	4	4	4	4	4	4	0	0	0	0	0	0	0	0
	4	/	/	/	/	/	/	3	2	3	6	2	4	6	1
		0	0	0	1	2	3								
		4	7	8	7	0	0								
AEB-M	1	1			1			1	1			2		2	
AEB-AP	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1
AEB-A&P/S	1	1	1		1		1	1	1			2	1	1	2
AEB-AS		1			1			1	1						2
CAM-M(C)	1	1	2		1		2	1	1			2	2	1	2
CAM-F.M.	1	1	1		1		1	1	1	1	1	2	1	1	1
JMB-ASP&M	1	1			1			1	1				2	2	
JMB-P&M	1	1	2		1		1	1	1			2	1	1	2
JMB-P&A	1	1	2	1		1	1	1	2	2	1	2			
JMB-F.M.	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1
LON-M(B)	1	1			1		1	1	1			2	1	1	2
LON-AP.M.	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1
LON-F.M.	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1
MEI-M	1	1	2		1		1	1	1	1	1	2	1	1	1
MEI-F.M.	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1
OXF-P&A	1	1			1			1	1			2	2	1	2
OXF-P&M	1	1	2		1		1	1	1			2	1	1	2
OXF-F.M.	1	1	1		1	2	1	1	1	1	1	2	1	1	1
O&C-AS	1	1						1					2	2	
O&C-M	1	1	2		1		1	1	1	1	1	2	1	1	1
O&C-F.M.	1	1	2		1		1	1	1	1	1	2	1	1	1
SMP-M	1	1	2		1		1	1	1			2	2	1	2
SUJB-AS	1	1						1					2	2	
SUJB-AP	1	1	1		1		1	1	1	1	1	2	1	1	1
SUJB-P&A	1	1	1		1		1	1	1			2	1	1	2
WJEC-M(M)	1	1	1		1		1	1	1			2	1	1	2
WJEC-AP	1	1	1		1		1	1	1			2	1	1	2

1 Programme Completely Relevant To Syllabus

2 Parts Of Programme Relevant To Syllabus

Table 123 - The Relevance of Open University Programmes to A-Level Syllabuses

	Module Number									
	1	2	3	4	5	6	7	8	9	10
AEB-M	1	1	1	1	1	1				
AEB-AP	1	1	1	1	1	1	1	1	1	1
AEB-A&P/S	1	1	1	1	1	1	1	1	1	1
AEB-AS	1	1			1	1				
CAM-M(C)	1	1	1	1	1	1				
CAM-F.M.	1	1	1	1	1	1	1	1	1	1
JMB-ASP&M	1	1	1	1	1	1				
JMB-P&M	1	1	1	1	1	1	1	1	1	1
JMB-P&A	1	1	1	1	1	1	1	1	1	1
JMB-F.M.	1	1	1	1	1	1	1	1	1	1
LON-M(B)	1	1	1	1	1	1	1	1		
LON-AP.M.	1	1	1	1	1	1	1	1	1	1
LON-F.M.	1	1	1	1	1	1	1	1	1	1
MEI-M	1	1	1	1	1	1	1	1	1	
MEI-F.M.	1	1	1	1	1	1	1	1	1	1
OXF-P&A	1	1	1	1	1	1				
OXF-P&M	1	1	1	1	1	1	1	1	1	
OXF-F.M.	1	1	1	1	1	1	1	1	1	1
O&C-AS	1	1	1	1						
O&C-M	1	1	1	1	1	1	1	1	1	
O&C-F.M.	1	1	1	1	1	1	1	1		
SMP-M	1	1	1	1	1	1	1	1	1	
SUJB-AS	1	1	1	1						
SUJB-AP	1	1	1	1						
SUJB-P&A	1	1	1	1	1	1	1	1	1	1
WJEC-M(M)	1	1	1	1	1	1	1	1	1	1
WJEC-AP	1	1	1	1	1	1	1	1	1	1

1 Programme Completely Relevant To Syllabus

Table 124 - The Relevance of Visualizing Mechanics Video Tapes to A-Level Syllabuses

"Modelling Cranes" ***

Open University (1978), M101/24, Colour, 25 Minutes.

This video forms part of a series of programmes on mathematical modelling, and follows a series of steps that have been defined in an earlier programme. There is no need however for the students to be familiar with these steps if they are to watch this video.

The initial part of the programme presents a real problem that has to be solved. This is to find the force that is exerted on the ground by two stays that form part of a crane. A simple working model of the crane is produced in the studio and its action demonstrated. A 2D diagram of the crane is then used to identify the forces acting for a specific jib position and load. The force in one member is then found, making the assumptions that the members of the crane are light and pin-jointed. The approach taken is using a parallelogram of forces and a geometric approach.

The model is then used to verify that the predicted force is actually the same as the one in the model by using spring balances to measure the tensions in the model crane. The analysis then continues, moving from joint to joint, until the required force has been found. As the analysis progresses the video moves between the working model and 2D diagrams. All the predictions are made using geometric arguments based on a parallelogram of forces.

A crane manufacturer is then introduced and he explains how the process used in the programme is very similar to that used in his design office, as a first step in crane design.

Finally the programme looks at a more sophisticated model of a crane. This however becomes unstable and collapses at certain positions of the jib. An analysis of this crane is undertaken and a prediction made as to when it will collapse. This prediction is then verified using the working model.

This video has a potential for use with all sixth form students. It provides good examples of the way that forces are modelled and combined, ideas that are particularly important to develop in a statics environment.

"Newton's Equation Of Motion" ***

Open University (1982), MST 204/04 (Associated Text MST204 Unit 4),
Colour, 24 Minutes

This video is an introduction to Newton's first two laws of motion and considers particularly the equation of the second law. It starts by simply stating all three laws and then looks at the history that led up to their formulation, with Aristotle stating his laws of motion and then being challenged and replaced by Newton. Consideration of a horse and cart shows how it was thought that a force was needed to maintain motion, but that the friction involved was misleading, so the video moves to an ice rink to study motion with little friction. An ice puck is seen here moving in a straight line with constant velocity until a force is applied to change its direction, which leads to the statement of Newton's first law.

The programme then moves into the studio, to look at the equation that Newton said related force and acceleration. A glider on an air track illustrates the first law in the absence of friction. A force is then applied to the glider and a graph of position against time is drawn. Using tangents this is then used to draw a velocity against time graph, from which the acceleration can be seen to be

constant and its value calculated. In a second experiment the force is doubled and the acceleration is also doubled, with the calculation of the acceleration being left for the viewer.

The part that mass plays in the relationship is then explored. A glider of twice the mass is used in an experiment, which shows that the acceleration has been halved. Newton's equation is then used to calculate the force used in the experiments. It then demonstrates how the mass of an object can be found by applying the force to a glider of unknown mass, its acceleration is measured and from this its mass is calculated. The air track is then used without applying the force, but tilted slightly so that gravity effects the glider. From measurements of the acceleration the force acting on the glider is then calculated.

The presenter then explains how the real power of the equation lies in its ability to make predictions about motion. He considers the case of the glider on the tilted air track with the force acting on it. The net force on the glider is calculated before the experiment is performed, and the viewer is left to confirm that the acceleration measured agrees with the predicted force. Finally the video concludes by saying that Newton's laws can be applied in most situations, but that all the forces acting must be included, and these will often include friction.

I would strongly recommended the first part of this programme for use with all sixth formers, particularly as it considers an intuitive idea that they may already have and attempts to discredit it. However I would suggest that teachers would be advised to use the first two modules of "Visualizing Mechanics", which split this programme into two parts.

"The Fabulous Perfect Spring" **

Open University (1982), MST204/07 (Associated Text MST204 Unit 7), Colour,
24 Minutes

A spring which oscillates perpetually with simple harmonic motion is used to start this video. Animated diagrams illustrate the motion of the spring from different starting points. The equations of motion are derived in two ways, the first by looking at the forces acting and producing a differential equation. A solution, in the form of a cosine function, is then given and explained. An expression for the period of oscillation is derived, and it is noted that this is always the same for any particular spring. The terms amplitude and phase are also explained at this stage, with animated demonstrations of two identical springs, that have different starting points.

Experiments on an air track then demonstrate some of these properties. The period of a spring is shown to be the same whether it is vertical or horizontal. However varying the mass or stiffness changes the period.

An alternative analysis of the motion is then undertaken using energy considerations. This is based on the fact that the total energy of the system is a constant, made up of the sum of the kinetic energy of the mass and the potential energy of the spring. Integration of the force in the spring is used to find this potential energy function. From these results an energy conservation equation is formed. Animated graphs are used to illustrate the potential and kinetic energies, separately first, and then together.

Situations where motion is not in a straight line are then analysed by studying the interchange of potential and kinetic energy. The video shows that the motion

of a car on an undulating track appears to be simple harmonic near points where potential energy is a minimum. An energy equation is derived, and Taylor's expansion is applied to the potential energy function. This produces an approximate expression, which has exactly the same form as the energy equation for the perfect spring. The expansion is approximate and can only be used for oscillations with small amplitudes. The calculation of the period is outlined. This equation of motion is then applied to the car. The video explains that if the track were a cycloid then the motion would be exactly simple harmonic. This is illustrated by comparing the period of two cars moving on a track with different amplitudes. The motion of a pendulum is also considered, being approximately simple harmonic, provided that the amplitude of the oscillations is small. The presenter explains that the pendulum can only have true simple harmonic motion if its path is a cycloid, and a modified pendulum with this property is demonstrated.

I would not recommend this programme as it stands is used with sixth formers, following a single subject course. The ninth module of "Visualizing Mechanics" would be more appropriate. I feel that the non-linear simple harmonic motion covered in the second part of the programme goes beyond the needs of most A-level students.

"Off The Record: Resonance And Damping" ***

Open University (1982), MST204/08 (Associated Text MST204 Unit 8), Colour,
24 Minutes

This video looks at vibrating systems in which damping and forcing are present. Playing a warped record is used as an example of forced vibrations. The effects of damping are explored first by experiments using a spring supporting a mass

that vibrates on its own with almost constant amplitude. A dashpot (a piston in a cylinder) is then fitted to the mass with the cylinder first left empty, then filled with water and finally with oil. The air had no effect, while the water reduces the amplitude and the oil causes the spring to move immediately to its equilibrium position.

An analysis of the motion is then undertaken, starting initially with a diagram showing the forces which leads to a differential equation, which is then solved. In the solutions a constant, known as the damping factor, is identified. How the value of this constant determines which of three possible effects the damping could have, is then explained. The video returns to the experiment and traces are taken to record the oscillations. The student is left the task of confirming that they fit the theoretical model.

Forced vibrations are then investigated, with apparatus that produces vibrations and also incorporates a dashpot for damping. The forcing frequency is varied to demonstrate that resonance occurs at a certain frequency. The theory of these vibrations is then analysed by starting out with a diagram, forming a differential equation and solving it. In the solutions the amplitude of the forced vibration is shown to depend on the value of the damping factor and graphs are used to illustrate how the resonance fades away with increased damping. One of these graphs compares well with the results from the experiment. By increasing the amount of damping in the experiment, it is shown that the resonance completely disappears.

The video then returns to the case of the record player and the presenter outlines the analysis of this motion, leaving the student to attempt it later. The graphs of the solutions are shown for different damping factors, and how these apply to the situation of the record player is explained. Finally a miniature damper is fitted to

the arm of the record player, which increases the damping so that the record plays perfectly.

This programme is recommended for students who are following courses that include the study of forced and damped vibrations.

"Projectiles - Motion In More Than One Dimension" ****

Open University (1982), MST204/17 (Associated Text MST204 Unit 15),
Colour, 24 Minutes

The problem posed at the beginning of this video is to find what effect the speed, angle and height of release have on the distance a shot putt travels, by using Newton's laws in two dimensions. A shot putter is shown in action, with the path of the shot after release.

The video then moves to the studio where a puck on an air table is used to simulate the motion of the shot, but at a much slower speed so that it can be studied. A comparison of the accelerations of the puck and the shot illustrate the degree to which the motion has been slowed down. It can be seen that the puck has a parabolic path, which is then compared with that of the shot.

An analysis of the motion is then carried out, starting with the force on the shot and obtaining equations for its path, initially with components in terms of time, which is then eliminated. Thus it is deduced, that the motion of an object acted on only by gravity, moves in a parabolic path. The air table is then used to demonstrate the presence of an acceleration in the vertical direction and the absence of any in the horizontal direction.

The shot putter will always try to give the shot the maximum possible velocity, so the effect of varying the angle of release on the shot is considered, assuming that it starts from ground level. Experiments are used to find the angle required for the puck to have a range of one metre. The equations for the x and y components of motion are considered again, to obtain expressions for the angle of release and the range. These are used to confirm the value of the angle from the experiment, and to predict another angle that will give the same range, which is checked by a further experiment. A computer animation then shows that there are two pairs of angles giving the same range, except for forty five degrees when the maximum range is achieved. This value is confirmed by looking at the expression for the range obtained earlier.

Finally the height of the shot putter is brought in. Raising the starting point extends the range and this is now demonstrated on the air table. The angle for the maximum range has now changed, being less than before, which is demonstrated by looking at the two paths. The presenter explains why the greater horizontal velocity of the shot with the smaller angle causes this. Finding the size of the angle for the greatest range is left as an exercise for the students.

This programme provides an excellent analysis of projectile motion and is strongly recommended for use with all sixth form students.

"Tops, Gyroscopes And Angular Momentum" ***

Open University (1982), MST204/20 (Associated Text MST204 Unit 29),
Colour, 24 Minutes

This video begins by looking at a spinning top and asking why it balances, even when it is not in an upright position. The persistence of this rotation is

reminiscent of Newton's first law for linear motion. To try and build up an understanding of this a single particle within a body is considered, and its angular momentum defined as the vector product of its position vector and its linear momentum. With more than one particle it is defined as the sum of the angular momentum of all the particles.

A bicycle wheel spinning about a vertical axis is used as an example. By considering the angular momentum of two points exactly opposite each other, it is deduced that the total angular momentum must be a constant vector directed along the axis of rotation. The wheel is then displaced so that it no longer horizontal, and the axis can be seen to precess, so that a point on the axis moves in a circle. Thus the angular momentum is no longer constant, and an investigation of this situation follows.

The rate of change of angular momentum is derived and found to be equal to the vector product of the position vector and the external forces, which is known as the torque. The video then returns to the bicycle wheel, so that the forces on it and hence the torque can be identified. These are used to explain how the torque causes the axis to precess. The case of the vertical axis is then considered, and because there are no torques present it will not precess, as with the spinning top example.

The video then looks at gyroscopes. Experiments demonstrate the difference of applying a force to a still and a rotating gyroscope. To explain why the second one precesses the torque on it is identified. Another gyroscope, which has been fitted with springs, is used to show the effects of rotating it with the result being explained using the vector cross product.

The final section of the video looks at a practical use of gyroscopes in a cross channel ferry. Here one is used to monitor the roll of the ferry and to control stabilizers.

Parts of this programme would be relevant to students following further mathematics courses. It takes an interesting look at angular momentum applied particularly to gyroscopes that I would recommend for use with able students.

"Newton's Third Law" *

Open University (1982), MST204/30 (Associated Text MST204 Unit 17),
Colour, 24 Minutes

This video aims to study the motion of systems of particles and to introduce Newton's third law, the centre of mass, linear momentum and the conservation of momentum. Two gliders, joined by a spring, on an air track display a complex motion, while the centre of mass of the system moves very simply, with constant velocity. An analysis of this motion is undertaken, using Newton's second law and Hooke's law, which shows that the acceleration of the centre of mass is zero and thus that its velocity is constant. A prediction is then made for the centre of mass of a system with unequal masses, which is confirmed by an experiment. The theory is also used to predict that the centre of mass of a system will move with the same acceleration as a single mass when it is acted on by the same force. This is verified using a tilted air track to provide the force.

To show that these results are not unique to springs, an experiment is repeated using magnets to provide the forces rather than springs. The presenter explains that the forces between the particles are equal and opposite, which is Newton's third law. This is then taken further by considering two particles in three

dimensions. Newton's third law is used to derive the result, that the sum of the external forces is equivalent to the total mass multiplied by the acceleration of the centre of mass. Two pucks, joined by a spring and moving on an air table, demonstrate how a complex motion can be simplified by considering the centre of mass, which moves as though it were a single particle.

The video then turns its attention to the case where no external forces are present, to show that the total linear momentum is constant. This is very useful in the study of collisions, and an experiment using two identical pucks on an air table demonstrates this. By taking components a prediction is made, which is then confirmed when the experiment takes place. To extend the use of this principle further, the conservation of kinetic energy in an elastic collision is introduced. The presenter sets a problem for the student to find the relationship between the two masses and the angle of scattering. He outlines the procedure needed and uses the result to predict the angle between the directions of motion for two identical masses, after a collision. This result is confirmed by an experiment. How this process can be used in reverse to find the relative masses of two particles is then described, with examples from atomic physics. A detailed explanation, of what happens when a small mass hits a much larger one, is given, and how this was important in the early days of atomic physics.

This programme is not recommended as it covers too much at once and not as well as some alternative programmes. The seventh and eighth modules of "Visualizing Mechanics" cover the same material in smaller sections that are easier to digest. Alternatively there are other video materials that could be considered.

"Motion-Newton's Laws" **

Open University (1978), S 101/03, Colour, 25 Minutes

This video starts by looking at how motion in a space station and motion on Earth do not seem to obey the same rules. But by examining how Newton's laws apply it is possible to see that the same rules do work in both situations. An experiment involving the dropping of a hammer and a feather illustrates how the effects of gravity and air resistance complicate motion, and explain why it took so long to establish the laws of motion in the first place. The presenter at this stage refers to a problem in the accompanying text about the density of the moon.

To illustrate Newton's laws more clearly the effects of gravity and air resistance need to be removed, which can be done by using a horizontal frictionless surface, such as an ice skating rink. Experiments here show how the laws work, firstly showing that in the absence of any external forces a skater moves in a straight line. The second law is illustrated by applying the same force to two skaters of different masses and calculating their resultant accelerations. This process is complicated slightly by the use of elastic to provide the force, but this is carefully overcome. The third law is demonstrated by having one skater push against another and it can be seen that equal and opposite forces are exerted on both and that the lighter one has the greatest acceleration.

In the studio an air track is used for further experiments, where collisions occur. The video explains that in this case it is more appropriate to use the principle of conservation of momentum and this is illustrated by measuring velocities before and after the collision.

The difference between motion on earth and in space is then taken further with a model to simulate an object in orbit, using a puck on an air table attached to a fixed point with a spring. The presenter also explains how any object in a space station can be considered to be in its own orbit around the earth.

Although this programme provides a good overview of Newton's laws I would recommend that each law is treated separately using some of the other materials that are available.

"Acceleration At Constant Speed ?" ****

Open University (1983), S 271/02V, Colour, 24 Minutes

The video starts by illustrating ways of indicating the presence of an acceleration using a pendulum or a container of water. It describes how we expect to experience acceleration when we are speeding up or slowing down. The idea of acceleration at constant speed is then introduced by using a circular table rotating at a constant rate. A pendulum is used to show the presence of an acceleration, which is subsequently referred to as centripetal acceleration. The concept of centripetal acceleration is expanded further by considering an object moving around the earth. The rotating table is then used again to show how the distance from the centre of rotation and the rate of rotation effect the magnitude of the acceleration.

The question of how to find the magnitude of the centripetal acceleration is then asked. A puck on a length of string rotating about a fixed point is used as an example. The definition of average acceleration is used and this leads to a numerical value for the acceleration as the time interval is reduced. A more

general approach is then followed which takes the limit of the expression for the average acceleration and leads to the formula, mv^2/r .

Some examples of circular motion are then examined and calculations are performed using the formula. These examples look at the creation of artificial gravity in a space station, and the acceleration experienced by a pilot "looping the loop" in an aeroplane. A force is needed to create this acceleration and the presenter identifies this force for each example.

Finally the video illustrates what happens in the absence of a force causing the centripetal acceleration, by cutting the string attached to the rotating puck used earlier in the programme.

I would strongly recommend this programme as being particularly important for all students studying circular motion. My only reservation lies with the use of the term "centripetal acceleration".

"Energy To Go Round" ****

Open University (1983), S271/03V, Colour, 23 Minutes

This video starts by looking at examples of how flywheels are used as stores of energy. These are illustrated by a toy car, an old steam pumping engine and how with a diesel engine a flywheel helps run a bus more efficiently. The question "How much energy does a flywheel store?" is then asked.

In the studio an experiment is set up using four masses on a windmill. It shows how the kinetic energy of a flywheel depends on the distribution of the masses. The kinetic energy of each mass is deduced, and then combined to give the

energy of the whole system. This idea is then extended to find the kinetic energy of any body and the concept of moment of inertia is introduced.

The video then moves to the design of flywheels for use in buses where it is required to store the maximum amount of energy. The researcher explains why the mass of a flywheel needs to be kept to a minimum, and so therefore very high angular velocities are used. However these can lead to flywheel disintegration, and bring passenger safety into doubt. The presenter then explains in the studio why this can occur. The researcher then shows the results of disintegration on various flywheels, and explains the measures that can be taken to overcome this problem.

This is an excellent programme that I would strongly recommend for all students who need to cover moments of inertia. I particularly liked the strong emphasis on the applications of the mechanics.

"Juggling With Physics" *

Open University (1983), S 271/06V, Colour, 24 Minutes.

This video aims to illustrate and revise some of the concepts that students will have encountered, by looking at examples of mechanics at a circus. The motion of many things here is very complex and the presenter explains how they need to be simplified if they are to be analysed. The first example shows that the centre of mass of a tennis racket that rotates when it is thrown can be seen to move in a parabola, as if it were a point mass.

A ball dropped from a height is compared with a ball thrown horizontally from the same height, to show that the horizontal and vertical motions are

independent. This is used to introduce the resolving of velocity into components. This technique is then used with forces, and is applied to a man on a tightrope where horizontal and vertical components are used to find the tension in the wire. This process is well illustrated with vector diagrams. However in the case of the tightrope, the video explains that it is also necessary to consider the torques that are acting on the man if he is to remain on the rope.

Often, rather than using Newton's laws, it is desirable to use the principles of conservation of energy or momentum. The video illustrates why these principles cannot always be used. However the expression for the work done by a force is used, in a qualitative rather than a quantitative way, to analyse motion.

A rotating acrobat is then examined and the relationship between her rate of rotation and her angle to the vertical is explored. This is then illustrated by watching the angle change as she slows down. The importance of torques is then considered further by looking at people on the tightrope and the techniques that they use to help keep their balance.

This is an unusual programme that I feel would have limited value in the classroom, as it covers so briefly a wide range of concepts, some of which go beyond most A-level syllabi. For this reason I would not recommend its use.

"Free Body Diagrams" ***

Open University (1979), T232/02, Colour, 25 Minutes.

This video aims to find the forces in two members of a pin jointed structure. It first sets the problem, using examples, and then develops the technique of using free body diagrams in situations of equilibrium.

Three free body diagrams are drawn for a ship, a horizontal spring and a vertical spring supporting a mass. The difference between mass and weight is then explored and illustrated by comparing the value of g on the earth and on the moon. Frictional forces also are considered, first by looking at a body on a slope and its free body diagram, which shows that a frictional force must be present. A spring balance used to pull a mass on a horizontal surface illustrates limiting friction. Consideration of the free body diagram then introduces the idea of coefficient of friction and the relationship between the normal reaction and friction.

A problem is then considered that involves the forces on a mass when immersed in water. A free body diagram gives a value for the buoyancy, which is then confirmed by experiment. The causes of this buoyancy force are also examined.

The video then returns to the pin jointed structure and demonstrates how to measure the force in its members, using strain gauges. Moments and the principles of equilibrium are then used to calculate the external forces on the structure and these values are confirmed by a spring balance supporting the structure. A free body diagram is then drawn for the joint concerned and the forces in the members attached to the joint are found by using components. Finally the strain gauges are used to verify these values.

This is a programme that I would particularly recommend for students studying statics but it is also valuable for all students of mechanics. I liked the way in which the theory was applied to a real problem.

"Dynamic Analysis" ****

Open University (1980), T232/04, Colour, 25 Minutes.

This video sets out to show how mechanics can be used to solve two engineering problems, using dynamic analysis. The first is to find the forces acting on a gudgeon pin in an engine, and the second is to find the minimum safe rate of rotation for a fairground ride.

The components of the engine are explained along with its operation. A look is taken at a real fairground ride which is simulated by a model in the studio. Before any analysis takes place the viewer is reminded about Newton's second law.

The analysis then takes place along the lines set out in the programme notes, which students are expected to be familiar with. This procedure is explained and consists of; assembling the information, drawing a free body diagram, applying Newton's second law, looking at the kinematical restraints, evaluating the forces and combining all this to form an equation of motion. From this equation the required values can be calculated. The video alternates between the two problems showing how the solutions are obtained. It finishes by demonstrating the validity of the solution for the fairground ride using the model.

This is an excellent programme that illustrates real applications of mechanics and shows how these can be tackled using a sixth former's knowledge. I would strongly recommend this programme to any teacher using a course that includes vertical circular motion.

"Work, Energy, Power" **

Open University (1981), T232/06, Colour, 25 Minutes

This video looks initially at the transfer of energy and uses this to introduce the concepts of work done and power. First the raising of a mass is used to show how work done is defined and that its magnitude can be calculated by using force multiplied by distance. Two equal masses are then raised at different speeds to the same height, illustrating the idea of different work rates. Power is then defined as the rate at which work is done, and examples are given to show its value in different situations. Gravitational potential energy is then defined and examples show how this can be transferred from one mass to another. Kinetic energy and spring potential energy are introduced and the former considered in some detail, to arrive at an expression for its value.

The video moves on to apply these concepts to flywheels. By comparing rotational and translational motions, an expression for the kinetic energy of a flywheel is deduced. An experiment in the studio demonstrates the transfer of potential energy from a mass as it falls to the kinetic energies of the mass and a flywheel. The data, obtained from this experiment, is then used in calculations to find these energies. Several examples of applications of flywheels are then considered in toy cars, buses, trains and satellites in space. When using flywheels as energy stores, it is desirable to reduce friction and air drag as much as possible. Examples show how this can be done by using magnetic bearings and operating in a vacuum. The energy that could be stored in one particular industrial flywheel is calculated.

An interesting video that I would recommend with some caution due to the way in which some concepts and definitions are introduced, especially when

rotational motion is compared with translational motion. However, in its favour, it does look at good examples of the application of energy concepts in flywheels. I would suggest that teachers particularly interested in rotational motion consider S271/03 as an alternative.

"Motion And Newton's Laws" ***

Open University (1983), T281/01, Colour, 25 Minutes.

This video shows how the simple ideas of Newton's laws can be applied to real objects with some quite complex motions, in particular non-rigid bodies in one plane.

The first example considered is a girl jumping on a trampoline. In this motion she moves up and down in a straight line, with her heights being recorded at various time intervals. These are plotted on a graph of height against time. A predicted graph is then produced, which compares well with the actual motion.

This motion is much more complicated, when she performs various manoeuvres in the air, so that she is no longer moving up and down in a straight line. This problem is resolved by looking at her centre of mass. Several shapes are used to illustrate how the centre of mass can be found, including examples when it is outside the body. The motion of the girl is then simulated on a computer, which shows how the centre of mass moves during the various manoeuvres, and that this point does actually move in a straight line. The conclusion reached, is that the centre of mass does fit Newton's laws.

Further examples look at high and long jumpers, where both horizontal and vertical motion take place. These situations are analysed using perpendicular

components of velocity that are shown to be independent. Simplification of the problem is therefore achieved as each component can be considered separately.

The forces involved in the take off when jumping are then considered. The effects of gravity and the normal reaction are examined for a person standing still. How these vary in different situations is illustrated using a pressure plate and these observations are explained by looking at the velocities and accelerations involved. The video concludes that much of the motion around us can be simplified in order to apply Newton's laws to it, but that there are a few exceptions, notably circular motion

A very good introduction to the concept of the centre of mass and strongly recommended for this reason.

"Visualizing Mechanics - Newton's First Law" ****

Open University (1983), Colour, 7.5 Minutes

Newton's laws of motion are now considered very important, this video begins by stating these laws and looking at the history of their formulation. It describes how the search for laws governing motion developed from those that Aristotle laid down. These remained unchallenged until the period of the Renaissance when they became discredited and eventually replaced by Newton's laws of motion.

The video considers why it was thought that a force was needed to maintain motion, but that this was not the best way to consider motion. A horse and cart illustrate this argument. An ice rink is then used to provide an almost frictionless surface, where ice pucks move with almost constant velocity in a straight line.

The presenter then explains Newton's first law, and how it applies to this example. Finally the video demonstrates how when an external force is applied the motion changes.

This module is strongly recommended for use with all sixth formers.

This sequence is taken from the Open University programme MST204/04.

"Visualizing Mechanics - $F=ma$: Newton's Second Law" ***

Open University (1983), Colour, 16 Minutes

The video is based on experimental work in the studio, to look at the equation that Newton said related force and acceleration. A glider on an air track illustrates the first law in the absence of friction. A force is then applied to the glider and a graph of position against time is drawn. Using tangents this is then used to draw a velocity against time graph, from which the acceleration can be seen to be constant and its value calculated. In a second experiment the force is doubled with the result that the acceleration is also doubled, with the calculation of the acceleration being left as an exercise for the viewer.

The part that mass plays in the relationship is then explored. A glider of twice the mass is used in an experiment, which shows that the acceleration has been halved. Newton's equation is then used to calculate the force used in the experiments. The video then demonstrates how the mass of an object can be found by applying the force to a glider of unknown mass, its acceleration is measured and from this its mass is calculated. The air track is then used without applying the force but tilted slightly so that gravity affects the glider. From

measurements of the acceleration the force acting on the glider is then calculated.

The presenter then explains how the real power of the equation lies in its ability to make predictions about motion. He considers the case of the glider on the tilted air track which also has a force acting on it. The net force on the glider is calculated before the experiment is performed, and the viewer is left to confirm that the acceleration measured agrees with the predicted force.

Finally the video concludes by saying that Newton's laws can be applied in most situations, but that all the forces acting must be included, and these will often include friction.

I would recommend this module for use with all students, although it is a little drawn out.

This sequence of video is taken from the Open University programme MST204/04.

"Visualizing Mechanics - Adding Vectors" ***

Open University (1983), Colour, 7.5 Minutes

This video aims to show that physical quantities can be represented by vectors and how they are added. It begins by looking at an example, (to be found in the booklet) of vectors representing displacements being added together.

Forces are then considered by using a practical demonstration. A ring is acted on by three forces, two of known magnitude applied through strings and one

unknown one from a peg that holds the ring in position. Vectors are used to represent the two known forces, which are then added using the triangle rule. Once their resultant has been calculated, an equal but opposite force is also applied to the ring. The peg is then removed to show that the resultant calculated was correct as the system remains in equilibrium.

Other applications of vectors are demonstrated by using them to model a spinning motion. The magnitude of the vector is the angular velocity and the direction is the axis of rotation defined by the right hand rule. Two examples are used to show that these vectors obey the triangle addition rule.

I would recommend that this module is used to extend students ideas of vector addition and illustrate their greater applicability, rather than as an introduction to the topic.

This sequence is taken from an Open University programme in the MS283 series.

"Visualizing Mechanics - Components Of A Vector" ***

Open University (1983), Colour, 9 Minutes

This video introduces the concept of a component of a vector and shows how these components can be added together. A practical problem, to find the forces that a mast exerts on a dinghy, illustrates why a numerical rather than a geometric representation of vectors is needed.

Two dimensional vectors are considered first, with a vector being broken down into its x- and y-components. The unit vectors i and j are introduced, so that the

vector can be described using them. An example of the addition of two vectors is used to demonstrate that vector addition can be carried out by adding components separately.

This concept of components is then taken to three dimensions, with the unit vector k . The video then returns to the dinghy. Spring balances show the tensions in the stays, which are also represented by vectors. As the problem is to find the downward force on the mast, the presenter explains that only the vertical components of the forces need to be considered. The vertical components are then added together to find the total downward force as required. The use of trigonometry to find the components in this case is briefly mentioned by the presenter.

The major weakness of this module is that it does not show how to calculate the components of a vector but produces them when they are needed. However I would still recommend this module because it clearly shows that a vector can be split into components and the advantages of doing this.

This sequence is taken from an Open University programme in the MS283 series.

"Visualizing Mechanics - Parabolic Path Of A Projectile"

Open University (1983), Colour, 11 Minutes

This module aims to analyse the motion of a shot, after it leaves a shot putter's hand. The video begins by looking at a training film for shot putters and tracing out the path of a shot.

The video then moves to the studio where a puck on an air table is used to simulate the motion of a shot, but at a much slower pace so that it can be studied. A comparison of the accelerations of the puck and the shot illustrate the degree to which the motion has been slowed down. From the experiments it can be seen that the puck has a parabolic path, which is then compared with that of the shot.

The equations for the acceleration and the position of the shot are given in terms of time, which is then eliminated to show that the path is parabolic. This process is explained fully in the booklet. The presenter then explains that any object, acted on only by gravity, moves with a parabolic path. This is illustrated by film of a motorbike stunt rider.

Finally the air table is used to demonstrate the presence of an acceleration in the vertical direction and the absence of any in the horizontal direction.

This module is strongly recommended. My only reservation is that the derivation of the equation of the path of the projectile is not as comprehensive as it was in the original programme (MST204/17).

This sequence is taken from the Open University programme MST204/17.

"Visualizing Mechanics - The Optimum Angle" ****

Open University (1983), Colour, 11 Minutes

This video follows on from the previous module, to try and determine how the factors speed, angle and height of release influence the distance the shot travels.

The shot putter will always try to give the shot the maximum possible velocity, so the effect of varying the angle of release on the shot is considered, initially assuming that it starts from ground level. Experiments on an air table are used to find the angle required for the puck to have a range of one metre. The equations for the x- and y-components of motion, from the previous module, are used again to obtain expressions for the angle of release and the range. These are used to confirm the value of the angle from the experiment and then to predict another angle that will give the same range. This calculation is checked by a further experiment. A computer animation then shows that there are two pairs of angles giving the same range, except for forty five degrees when the maximum range is achieved. This value is confirmed by looking at the expression for the range obtained earlier.

Finally the height of the shot putter is brought in. Raising the starting point extends the range and this is now demonstrated on the air table. The angle for the maximum range has now changed, being less than before, which is demonstrated by looking at the two paths. The presenter explains that the greater horizontal velocity of the shot with the smaller angle causes this. Finding the size of the angle for the greatest range is left as an exercise for the students.

This module is strongly recommended.

This sequence is taken from the Open University Programme MST204/17.

"Visualizing Mechanics - Systems Of Particles" *

Open University (1983), Colour, 11 Minutes

This video aims to study the motion of systems of particles and to introduce Newton's third law and the centre of mass. Two gliders joined by a spring on an air track display a complex motion, while the centre of mass of the system moves very simply with constant velocity. An analysis of this motion is undertaken using Newton's second law and Hooke's law which shows that the acceleration of the centre of mass is zero and thus that the velocity is constant. A prediction is then made for the centre of mass of a system with unequal masses which is confirmed by an experiment. The theory is also used to predict that the centre of mass of the system would move with the same acceleration as a single mass when it is acted on by the same force. This is verified by using a tilted air track to apply the force.

To show that these results are not unique to springs, an experiment is repeated using magnets to provide the forces rather than springs. The presenter then explains that the forces between the particles are equal and opposite, which is Newton's third law. This is then taken further by considering two particles in three dimensions. Newton's third and second laws are used to derive the result that the sum of the external forces is equivalent to the total mass multiplied by the acceleration of the centre of mass. Two pucks joined by a spring and moving on an air table demonstrate how a complex motion can be simplified by considering the centre of mass, which moves as though it were a single particle.

This module is not recommended for use with sixth formers. Much better treatments of its content are given elsewhere, particularly in the film "Action and Reaction" and the OU. programme T281/01.

This extract is taken from the Open University programme MST204/30.

"Visualizing Mechanics - Scattering Of Particles" ***

Open University (1983), Colour, 10.5 Minutes

This video concentrates on the case where no external forces are present to show that the total linear momentum of a system is constant. This is very useful in the study of collisions and an experiment using two identical pucks on an air table is now considered. By taking components a prediction is made which is then confirmed when the experiment takes place.

To extend the use of this principle further, the conservation of kinetic energy in an elastic collision is introduced. The presenter sets a problem for the student to find the relationship between the two masses and the angle of scattering resulting from a collision. He outlines the procedure needed and uses the result to predict the angle for two identical masses. An experiment confirms the result of this calculation, the full solution of which is in the booklet.

How this process can be used in reverse to find the relative masses of two particles is then described with examples from atomic physics. A detailed explanation of what happens when a small mass hits a much larger one is given, and how this was important in the early days of atomic physics.

Finally the video concludes by stressing the importance of the law of conservation of linear momentum.

This module contains the most interesting part of the MST204/30 programme and provides a good example of the use of the principles of conservation of momentum and energy. I would recommend its use with students who have studied both of these concepts.

This sequence is taken from the Open University programme MST204/30.

"Visualizing Mechanics - Simple Harmonic Motion" ***

Open University (1983), Colour, 10.5 Minutes

A spring which oscillates perpetually with simple harmonic motion is used to start this video. The differential equation governing its motion is deduced and animated graphs show its motion with different starting points. A solution in the form of a cosine function is then given and explained. An expression for the period of oscillation is derived and it is noted that this is always the same for any particular spring. The terms amplitude and phase are also explained using animated demonstrations of two springs that are identical but that have different starting points. Experiments on an air track then demonstrate some of these properties. The period of a spring is shown to be the same whether it is vertical or horizontal, while varying the mass or stiffness changes the period. An alternative analysis of the motion is then undertaken using energy considerations. The presenter explains that the total energy of the system is a constant made up of the sum of the kinetic energy of the mass and the potential energy of the spring. Integration of the force exerted by the spring is used to find this potential energy function. From these results an energy conservation equation is formed. Animated graphs then show the potential and kinetic energies, separately first, and then together.

This module is recommended. I particularly liked the animated graphs that showed the interchange of potential and kinetic energy.

This sequence is taken from the Open University programme MST204/07.

"Visualizing Mechanics - Oscillations And Energy" *

Open University (1983), Colour, 10.5 Minutes

This video begins by looking at the conservation of energy in simple harmonic motion and explaining how this can be used to analyse motions by studying the interchange of potential and kinetic energy.

The video shows that the motion of a car on an undulating track appears to be simple harmonic near points where potential energy is a minimum. An energy equation is derived and Taylor's expansion is applied to the potential energy function. This produces an approximate expression which has exactly the same form as the energy equation for the perfect spring derived in the previous module. The expansion is approximate and can only be used for oscillations with small amplitudes. The calculation of the period is outlined. This equation of motion is then applied to the car. If the track were a cycloid then the motion would be exactly simple harmonic. The video illustrates this by comparing the period of two cars moving on a track with different amplitudes.

The motion of a pendulum is also approximately simple harmonic provided that the amplitude of the oscillations is small. The presenter explains that the pendulum could only have true simple harmonic motion if its path were a cycloid, and a modified pendulum with this property is demonstrated.

I felt that this module goes beyond the needs of most A-level students. I would not therefore recommend its use with the majority of sixth formers.

This sequence is taken from the Open University programme MST204/07.

"Action And Reaction" ****

Iwanami/Bailey Film Associates(1970), Colour, 15 Minutes, 16mm or VHS

A number of identical springs are used in the first part of this film, to compare their extensions in different situations. Initially equal forces are applied to each end of the spring using weights. Then one of these is replaced with a flexible plastic strip and the viewer is asked to consider what will happen now. Two possibilities are shown before the actual outcome. The extension is still the same. The film explains that this is because the flexible plastic strip exerts a force equivalent to that of the original weights. A large plastic block is then used instead of the strip. The extension of the spring is still the same, implying that the block exerts a force on the spring. An optical technique is used to illustrate that the block does exert a force on the spring.

The weights are then increased, and the extension of the spring, although now greater, is still the same in each case. The deflection of the plastic strip is demonstrated to be the same whether the force is applied directly to it or via the spring.

The optical technique is used again when a plastic rod pushes against the block. It clearly shows that the forces present are equal but opposite. The law of action and reaction is then defined. An example examines the forces present when a block rests on two fulcrums, using the optical technique.

Some examples of action and reaction forces in everyday situations are used as illustrations. Finally a problem to find the easiest way to stretch a large spring is considered.

Although this film is very dated its illustration of pairs of action and reaction forces is so powerful that I would have no hesitation in strongly recommending its use with any group of sixth formers.

"Gravity, Weight And Weightlessness" ***

Bailey Film Associates (1985), Colour, 11 Minutes, VHS

This video begins with an introduction that looks at astronauts in NASA's skylab and the weightlessness that they experienced. The question "What is weightlessness?" is posed by the presenter.

The effect of gravity is demonstrated by dropping a carton of eggs onto the floor. Gravity is then defined as a force that pulls everything down towards the earth. The video goes on to explain that when things are pulled down against the earth they experience weight, but that if they are falling then they are weightless. This is illustrated with an animation that looks first at a set of weights on a spring balance on earth and then in free fall. Two examples of where humans might experience weightlessness are then described, the first on a roller-coaster ride and the second in a NASA research plane which dives to simulate weightlessness.

An imaginary experiment in which a canon fires a cannon-ball from the top of a very high mountain is used to illustrate how things can be put into orbit. The cannon-ball falls to the earth's surface in a curved path, the length of which

increases as the initial velocity of the cannon-ball increases, until it is fired fast enough to stay in orbit. This situation is explained by saying that the cannon-ball is trying to leave the earth but that gravity pulls it back to produce the curved path.

The video then returns to skylab and discusses the effects of weightlessness on the astronauts, liquids and fish taken into space. Finally the presenter summarizes the main points of the video.

I would recommend this thought provoking video which contains several interesting examples. I feel that it would be particularly valuable to use this with students who have just been introduced to the idea of the normal reaction.

"Movement Of The Centre Of Gravity" **

NHK International (1973), 9 Minutes, Colour, 16mm or VHS.

This film shows very vividly how the centre of gravity of an object has a simple motion, even though actual motion of the object could be very complex.

A rod with identical balls on each end is used initially. If it is held still and dropped its motion is very simple, but if it is rotating when released it is seen to have a very complex motion. The balancing point of the object is found and marked. When the motion is now repeated it is clear that this point falls straight down, as if all the mass were concentrated at this point. Another rod with different balls on each end is used next and again the motion appears very complex until the balancing point is considered. This point again falls in a straight line.

The objects are then thrown instead of being dropped. An animation is used to illustrate how the balancing point follows a parabolic path even though the object is rotating as it moves.

The film concludes by saying that the balancing point is called the centre of gravity and that the total motion is made up of the motion of the centre of gravity plus the rotational motion of the body.

I could recommend this film because of its clarity and simplicity, but a programme such as T281/01 provides a more interesting approach to the concept that could be used in addition or as an alternative to this film.

"Newton And The Shuttle" ****

BBC Television (1986), Colour, 20 Minutes, VHS.

This video illustrates the importance Newton's laws of motion by studying a mission of the space shuttle to repair a satellite in orbit around the earth. The mission and the reasons behind it are explained and Newton's laws illustrated where relevant.

Man has always been interested in the motion of the planets and activities on them and in space. A satellite that was sent up to observe the surface of the sun was now in need of repair. The space shuttle was to be launched and part of its mission would be the repair of this satellite and the launching of other new ones. The preparations for the launch are considered, including the training of the astronauts. One example of particular interest is the way in which a pool of water is used to simulate weightlessness.

The video then moves to look at the actual launch of the satellite, and says that although the technology would have seemed very strange to Newton, he would have been able to explain exactly what was happening. The principle of the launch is then explained by considering the recoil of a gun firing a bullet and the same gun firing without a bullet, which also recoils. The rocket is likened to the second case, but with a continuous stream of gases rather than a short burst.

The presenter explains how as the rockets are fired on the launch pad the force increases until it balances the weight of the rocket and then begins to overcome its inertia. As the rocket rises its acceleration increases as fuel is used and the mass of the rocket decreases. Finally when the shuttle is moving on its own it has much less mass and so less force is needed to make it move. The video then illustrates why the shuttle remains in orbit around the earth using the argument that it is always falling towards the earth but that the earth is curving away from it.

Once the shuttle is in orbit everything on board appears weightless, a phenomenon which is well illustrated. Although to the astronauts the shuttle appears to be still it is in fact moving. This means that to launch a satellite all that is necessary is to manoeuvre the satellites out of the cargo bay and release them, when they will have the same speed as the shuttle itself.

To reach the satellite needing repairs the shuttle first has to position itself in a higher orbit. The video explains how this is done by increasing the speed of the shuttle so that it spirals out to a higher orbit. Once there the shuttle manoeuvres itself, using forces only to start and stop its motion, but not to maintain it. This is also illustrated when the astronaut moves across space with the aid of a jet propelled back-pack. During the repair some of the problems associated with

working in space are illustrated, such as for example using a screwdriver or a drill.

Finally we see the return of the shuttle to earth, where it meets friction when it enters the earth's atmosphere.

This is an excellent programme that I would consider to be essential viewing for all sixth formers. Its strengths lie in the interesting story-line and the way it illustrates the importance of elementary mechanics in the exploration of space.

"The Tacoma Narrows Bridge Collapse" ***

Ohio University, Colour, Silent, 4 Minutes

This video is a copy of an amateur film made between 1938 and 1940. It includes film of the construction and the opening of the bridge before moving on to look at its collapse. The bridge is shown as its resonant oscillations develop and finally the breaking up of the bridge.

Although the picture quality is poor and there is no sound, I would recommend the use of this video, particularly in connection with the study of resonance.

"What Is A Force ?" ***

Coronet Instructional Films (1973), Colour, 10 Minutes, 16mm or VHS

This film concentrates on defining what a force is, by looking at examples where a force is acting. Four particular examples are used to build up the definition. The first using a sailing boat illustrates how a force can start a motion when it

causes a stationary object to begin to move. Secondly a drifting canoe that speeds up when paddled shows a force increasing the speed of a object. Thirdly a force is used to stop a motion when a boat comes alongside a jetty where it brought to a halt. Finally a water-skier is used to demonstrate how a force can be used to change the direction of motion. In all these examples the presenter explains how the forces overcome the inertia of the object concerned to produce a change in the motion. A force is then defined as something which causes a change in motion.

The original examples only considered one force, so the film now considers cases when more than one force is acting. For these the forces acting are identified before a conclusion is reached about whether or not they are in equilibrium. A motor boat is one of these, and the consequences of removing one of the forces is examined. The forces acting need not be present throughout the motion and this point is made by a description of the forces acting at different stages of a dive from a spring board.

I would recommend this film because of the approach it takes to defining a force. It is unfortunately quite dated, which could be a drawback when using it with sixth formers.

"Mechanics In Action" ****

University of Leeds (1990), Colour, 21 Minutes, VHS.

This video begins with a series of fast moving examples from the Alton Towers amusement park. The presenter raises questions such as how can we know that the rides will be safe. Having set these up as one example of mechanics in action other situations are also presented, such as Concorde taking off, a high speed

train and a motor cycle stunt. It also warns of the dangers of getting it wrong by showing the Tacoma Narrows Bridge collapse.

The video then moves to begin a look at Aristotle's three laws of motion and how these were eventually displaced by those of Newton. The first law considered is that a force is needed to maintain motion. Men pushing a car illustrate how this idea can seem reasonable, but then the motion of pucks and curling stones sliding on an ice rink is considered, and used to show the weakness of Aristotle's idea. The second of Aristotle's ideas considered is that the bigger the force the bigger the motion. A series of experiments first show how this argument was plausible and then discredit it. First a ball and a feather are dropped from a tall tower, then two balls of different masses and finally a hammer and a feather being dropped on the moon. The third of Aristotle's laws stated that the *force and motion* are in the same direction is examined using the help of a basketball. The video shows the direction that Aristotle would have said the force was acting in and then reminds the viewers that the force of gravity always acts downwards and so disproves Aristotle's argument.

The video then moves on to introduce *Newton and his laws of motion*. Several real examples including a ball rolling at constant speed and the rope in a tug of war with both teams at rest are used to explain the first law. Also an apple hanging on a tree is considered and the conclusion that Newton was right was reached. How friction complicates what we observe in reality is also dealt with at this stage. The video then looks at Newton's second law in a similar way by considering different examples. Observations of the affect of the force of gravity on a falling apple and the moon were what interested Newton and led to the formulation of his second law. A ball on the end of a piece of string being swung round in a circle, the moon orbiting the earth, as well as a falling apple are used to illustrate how Newton arrived at his law. Examples including a dragster and a

free falling parachutist are used to explain how the second law can be applied to everyday motion.

Finally the video considers circular motion, closing by showing how some of the rides at Alton Towers can be modelled using the Leeds mechanics kit. Several demonstrations are used and problems posed for the students to think about.

This excellent video is highly recommended for students who are about to begin a study of Newton's laws.

"Accident Investigation" **

Centre for Extension Education, University of Aston (1990), Colour, 35 Minutes, VHS.

This video begins by showing still photographs of an accident that was investigated by the local police force. The investigating officer explains the situation and the scene of the accident.

He then proceeds to lead the viewer through the police investigation of the accident. This is based around a scale drawing that was used in the investigation and he uses elementary mechanics and the principle of conservation of momentum to find the initial speed of one of the cars. The final conclusion that is reached is that one of the cars was travelling at 75mph in a 30mph speed limit. The calculations used are explained in great detail and there are regular points at which the teacher is recommended to stop the tape for class discussion.

The story that this video presents is in itself very interesting, but the pace at which it is presented and the frequent number of stops for discussion points

make it unsuitable for use with sixth form students. I would however suggest that using only the first few opening minutes to set up the problem and then allowing students to solve it themselves could be a valuable way of using some of this resource.

"Motion" ****

SMP / Centre for Teaching Mechanics (Plymouth, Polytechnic South West) (1990), Colour, 10.5 Minutes, VHS.

This video begins with a fast moving introduction that shows several different examples of motion. It then concentrates on one of these examples, a parachutist, who is seen to move in quite a complicated way, rotating as well as falling down to earth. This example is then contrasted with the motion of a puck in a game of ice hockey, which moves in a straight line between hits. From these examples the idea of a particle model is developed, particularly concentrating on particles moving along straight lines.

Having introduced this idea the video then moves on to consider the motion of a sprinter. The first step is to describe the assumptions made when modelling a sprinter as a particle and to pose a question asking the students to consider what point on the sprinter should be used to describe the position of the sprinter. The sprinter is then shown sprinting and the times at various stages of the sprint are recorded. A student is then seen to plot the data and find the gradient of one part of the graph and also the average speed for the whole sprint. The viewers are asked to discuss the differences between the two values obtained after watching the video.

The video then moves on to present two further examples, a swimmer and a motorcyclist, that provide data for the viewers to plot after watching the video. They are also asked to consider aspects of modelling this motion.

The video closes by presenting a number of examples of motion and asking the viewers to consider whether or not the particle model is appropriate for these situations.

This is a modern video produced specifically for the SMP Mathematics 16-19 course, but that would be of value to any students following mechanics courses. It would be particularly beneficial to those who have not studied physics at GCSE level.

"Introduction To Momentum" ***

SMP / Centre for Teaching Mechanics (Plymouth, Polytechnic South West) (1988), Colour, 9 Minutes, VHS.

The introduction to this video looks at a range of examples where momentum changes take place, either in collisions or when starting or stopping motion. From the introduction the idea of startability and stoppability are developed by looking at what factors make it difficult to stop a roller skater. Mass and speed are identified as the key factors.

A game of skittles is then used to take this investigation further. The video shows that a heavy ball knocks down a skittle easily at quite a low speed, while a much lighter ball needs to have a much greater speed if it is to knock down the skittle. From these experiments it is concluded that the product of mass and velocity is the most important factor in determining if the skittle will be knocked

down. Other factors involved in the collision between the ball and the skittle are also discussed.

A more controlled experiment using pucks that hover on a glass table is carried out in the studio. Two pucks of different masses are given identical pushes by jets of air. The pucks move with different velocities that are measured. The calculation of the product of mass and velocity for each puck is then carried out and leads to the same value for each puck indicating that they both have the same amount of this quantity.

Momentum is then defined more formally as the product of mass and velocity, with each of these terms being defined to ensure that there is no confusion in the students mind. The video explains that since velocity is a vector quantity then momentum must also be a vector quantity with magnitude and direction.

The video finishes with a second look at the car crash used in the opening sequence.

As this video is only a pilot it is not intended that it should be widely distributed, but it would be useful for students following courses that include momentum, but not conservation of momentum. For courses that do include conservation of momentum the video "Momentum and Collisions" would be more suitable and takes a similar approach.

"Momentum And Collisions"

SMP / Centre for Teaching Mechanics (Plymouth, Polytechnic South West) (1990), Colour, 10 Minutes, VHS.

The opening sequences of this video contain a number of examples of different collisions from real life situations. The video then moves to a studio shot of students undertaking an experiment involving collisions between trains on a track, that is part of the SMP written materials.

The video then explains how both the mass and the velocity of the objects involved in a collision are important. Mallets hitting tent pegs at different speeds are used to illustrate the importance of velocity, while a collision between a car and a lorry gives a dramatic illustration of the importance of mass. The focus of this first part of the video has been on collisions that take place in a straight line, which is then extended by raising the idea of oblique collisions.

Several examples are shown of oblique collisions, the final one being between two snooker balls. This collision is then analysed in some detail. The video concentrates on the velocities of the balls as their masses are equal. A slow motion replay shows the position of the balls at half second time intervals and from these velocity vectors for before and after the collision are drawn. These vectors are then manipulated to show that in this case the velocity is conserved.

The video then poses the problem of collisions using objects of different masses. Two air pucks of different masses are then used in a further collision, which is analysed in the same way as for the snooker balls. This shows that velocity is clearly not conserved in this case. An alternative approach, using vectors obtained by multiplying the velocities by the masses of the pucks, shows that

this quantity formed by the product of mass and velocity is conserved in collisions. The video then goes on to define this quantity as momentum and to stress its vector nature.

The video draws to a close with further examples of real life collisions. At the end of the video there are four problems that are presented on the video for the students to attempt.

This video is strongly recommended for any students who are about to be introduced to the principle of conservation of momentum.

OBTAINING VIDEO MATERIALS

1. Open University Broadcasts

Many schools and educational institutions already have licences to make off air recordings of Open University broadcasts. The courses referred to are listed below:

MST204	Mathematical Models and Methods
S101	Science : A Foundation Course
S271	Discovering Physics
T232	Engineering Mechanics : Solids
T281	Basic Physical Science for Technology

Details of these courses and television broadcast timetables can be obtained from;

The Open University,
Milton Keynes.

2. Visualizing Mechanics

This video-cassette and accompanying booklet can be obtained from the Open University at the address below. The cost of the tape and a booklet is £ 19-50.

Centre for Mathematics Education,
Open University,
Milton Keynes.

3. Other Videos And Films

Below are listed the suppliers of video copies of films and their addresses. The prices of video copies of films were correct at the beginning of 1989 and exclude VAT.

Film	Supplier	Price
"Action and Reaction"	D.S. Information Systems	£29-95
"Gravity, Weight And Weightlessness"	Viewtech	£46-00
"Movement of the Centre of Gravity"	D.S. Information Systems	£25-00
"Newton and the Shuttle"	BBC Enterprises	£125-00
"Tacoma Narrows Bridge Collapse"	Viewtech	£14-00
"What is a Force ?"	Viewtech	£32-00
"Mechanics in Action"	Mechanics in Action Project	£10-00
"Accident Investigation"	Centre for Extension Studies	£30-00

Table 125 - Suppliers and Prices of Videos

Details of BBC broadcast times can be obtained from the address below;

Education Information Assistant,
205 Villiers House,
Ealing Broadway,
London, W5 2PA.
Telephone 071 991 8024 or 071 991 8031

The addresses of the suppliers mentioned in the above table are listed below;

Viewtech Audio Visual Media,
161 Winchester Road,
Brislington,
Bristol, BS4 3NJ.
Telephone 0272 773422 or 0272 717030

DS Information Systems Ltd,
George Building,
Normal College
Holyhead Road,
Bangor, LL57 2HQ.
Telephone 0248 370144

BBC Enterprises,
Non-Theatric Film Sales,
Woodlands,
80 Wood Lane,
London, W12 OTT.
Telephone 071 743 5588

Mechanics in Action Project,
School of Mathematics,
University of Leeds,
Leeds, LS2 9JT

Centre for Extension Studies,
Aston University,
Birmingham, B4 7ET.

The British National Film and Video Catalogue may also be useful in tracing suppliers of films. It is produced by the British Film Institute and can be found in some libraries. The address of the BFI is given below:

British Film Institute,
21 Stephen Street,
London,
W1P 1P2

4. Centre For Teaching Mechanics Videotapes

These video tapes are still at a pilot stage and are being trialled as part of the SMP 16-19 course. If you are interested in these video tapes please contact the centre at the address below.

Centre for Teaching Mechanics,
Department of Mathematics and Statistics,
Plymouth, Polytechnic South West,
Drake Circus,
Plymouth,
PL4 8AA.
Telephone 0752 232772 or 0752 232773

Appendix B - The Teaching Package

This appendix contains a copy of the teaching package as used at Exeter College for the video experiment.

Motion - Teacher's Notes

1. Summary

The video considers the model of a particle moving in a straight line and the assumptions needed if it is to be used. The model is then applied to a sprinter, the assumptions being stated. Data is recorded as a sprint takes place and used to draw a distance time graph. The average speed of the sprinter is also calculated. Two examples are presented from which the student are expected to collect data to use in the exercises. Finally a number of short sequences are presented for which the students should discuss whether the straight line particle model is appropriate.

2. Video Teaching

It will be necessary for the students to have the worksheet before they start watching the video. Note that one of the times has been omitted from the summary table for the motorbike (40m, 6.12 s). After the video use the worksheets. Question 5 is intended to be treated as a topic for discussion.

0 m	0.00 s
20 m	3.24 s
40 m	6.12 s
60 m	9.04 s
80 m	11.88 s
100 m	14.80 s
120 m	17.84 s
140 m	20.80 s
160 m	23.76 s
180 m	27.28 s

Table 126 - Summary of Correct Times for the Motorbike

3. Non-Video Teaching

This should concentrate on introducing the idea of the straight line particle model, calculating average speeds and describing motion given a distance time graph. A different worksheet has been provided with the data from the video, so that the students can attempt the same exercises. Question 5 is intended to be treated as a topic for discussion.

4. Solutions

1. Average speed = 2.1 m/s. He moves very quickly to begin with and then with almost constant speed.
2. Its speed is almost constant. Average speed = 6.6 m/s
3. The curve represents the period of time when the sprinter's speed is increasing. The straight line indicates that the speed is constant.
4. His hands move relative to his body during the swim. This makes it difficult to see what is happening during the swim, but not at the end.

Motion - Exercises (Video)

1. The Swimmer - Record the data from the video on this table.

Distance Covered (m)	Time Taken (s)
0	
5	
10	
15	
20	
25	

Table 127 - Table for Question 1 of the Motion (Video) Exercises

After the video draw a distance-time graph and discuss how the speed changes during the swim. Also calculate his average speed.

2. The Motorbike - Record the data from the video on this table.

Distance Covered (m)	Time Taken (s)
0	
20	
40	
60	
80	
100	
120	
140	
160	
180	

Table 128 - Table for Question 2 of the Motion (Video) Exercises

After the video draw a distance-time graph for the motorbike. Calculate its average speed and explain why it is almost a straight line.

3. Explain why for the sprinter the distance-time graph is initially curved. What is the significance of the straight line ?

Explain why the average speed for the whole sprint will be less than the gradient of the straight line.

4. When recording the times for the swimmer his hands were used to judge his position. What problems could this cause for the person recording the times ?

5. Select some of the examples at the end of the video and answer these questions:

(a) Could the motion be modelled by the straight line motion of a particle ? If not suggest an alternative model.

(b) What assumptions must you make so the motion fits the model well?

Motion - Exercises

1. The table below gives the times recorded as a swimmer passes markers along the side of a twenty five metre pool. Draw a distance time graph for the swimmer and describe how his speed changes during the swim. Also calculate his average speed.

Distance Covered (m)	Time Taken (s)
0	0.00
5	1.02
10	3.14
15	6.04
20	9.20
25	12.07

Table 129 - Table for Question 1 of the Motion Exercises

2. The table below gives the times recorded as a motorbike passes cones placed at 20m intervals. Draw a distance time graph for the motorbike and explain why it is almost straight.

Distance Covered (m)	Time Taken (s)
0	0.00
20	3.24
40	6.12
60	9.04
80	11.88
100	14.80
120	17.84
140	20.80
160	23.76
180	27.28

Table 130 - Table for Question 2 of the Motion Exercises

3. The graph below is a distance time graph for a 100m sprint.

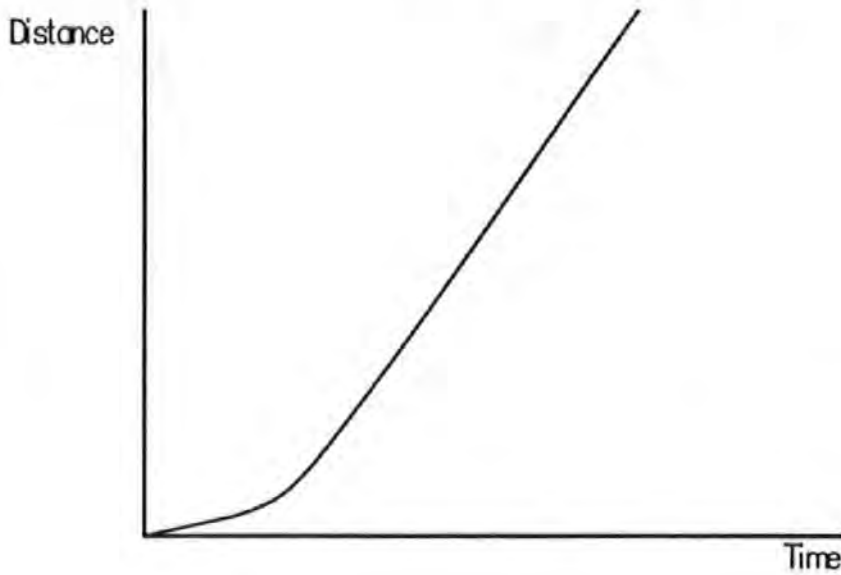


Figure 66 - Graph for Question 3 of the Motion Exercises

Explain why the graph is initially curved and the significance of the straight line. Explain why the average speed for the whole sprint will be less than the gradient of the straight line.

4. When recording the times for the swimmer his hands were used to judge his position. What problems could this cause for the person recording the times ?

5. Select some examples of motion in real life and answer these questions:

(a) Could the motion be modelled by the straight line motion of a particle ? If not suggest an alternative model.

(b) What assumptions must you make so the motion fits the model well?

Newton's First Law - Teacher's Notes

1. Summary

This video considers first the history of the development of Newton's laws and then discusses the first of these laws. Aristotle's ideas about force and motion were held for a very long period of time and are still intuitively developed by some students today. The video examines why it was thought that a force was needed to maintain motion. Newton's first law is examined on an ice skating rink where there is almost no friction. (Video length 7.5 minutes).

The exercises first compare Aristotle's ideas with Newton's laws and then make use of the first law. An additional sheet, for the teacher, outlines the laws of motion as defined by Aristotle and points to some of their weaknesses. These ideas will be useful to both the video and the non-video teachers.

2. Video Teaching

It may be valuable for the class to discuss some of the points on the video before proceeding to the exercises.

3. Non-Video Teaching

Newton's first law should be introduced and compared with Aristotle's idea, that a force was needed to maintain motion (see additional sheet).

It should be pointed out that friction often complicated the issue in that a force was needed to overcome friction. It would be useful to discuss the motion of objects on horizontal frictionless surfaces.

4. Solutions

1. (a) Yes, as it stops quickly. (b) No, as it continues to move for a long time.
2. No, Friction
3. Real life situations all involve some friction which will eventually stop the motion.
4. Constant, Any reasonable straight line, Constant, During contact with the stick, Never.
5. (a) Increasing (b) Constant (c) Yes (d) Vertical ones only, weight and the normal reaction.
6. 700 N
7. (a) No, weight (less air resistance). (b) Yes, since the resultant force on the book is zero. (c) Yes, since air resistance is equal to the weight. (d) No, the rails exert a force on the train wheels.

An Outline of Aristotle's Laws of Motion

The first attempt to lay down a set of laws governing motion was made by Aristotle. His laws were based on the statement:

$$\text{Velocity} = \text{Force} / \text{Resistance},$$

subject to the condition that the force must be greater than the resistance, if motion is to take place.

The resistance was a value associated with the reluctance of an object to move. Obviously this would be larger for a heavier object than it would be for a much lighter one. The condition was needed to explain why one man could not make a very heavy object move at all, while a group of men could push it.

Aristotle was well aware that his law was not universally applicable as it stood, but had supported it with qualifying statements for particular situations, such as falling and projectile motion.

The laws can be summarised by saying that if a force is applied to an object, then motion will only take place if the force is larger than the resistance. If motion does take place then the velocity will be proportional to the force applied. However as soon as the force is removed the motion of the object will stop.

In certain situations, particularly where there is a lot of friction present, Aristotle's laws seem plausible, but in others they are much more easily discredited. As an example consider a heavy cart that is being pushed. When you stop pushing it stops quickly, apparently confirming what Aristotle said. However what really happens is that the friction forces present, that were equal to the force provided by your pushing, stop the cart. Compare this with a

situation where there is little or no friction. If you slide something across a smooth icy surface it will continue moving for a long time after the force that caused the motion is removed. This clearly does not agree with Aristotle's law.

If you apply a constant force to an object it will begin to move and its velocity will continue to increase until the force is removed. This clearly does not agree with Aristotle's ideas, which would expect the velocity to be constant.

These are just a few examples of deficiencies in Aristotle's laws, and many more can be identified. The major difference between these and Newton's laws is that Newton saw that forces caused changes in motion, while Aristotle thought that they were necessary to maintain motion.

It has been shown by research studies that many students develop their own ideas about motion derived from their experiences of the world around them. These ideas often closely resemble Aristotle's basic law of motion, in that they feel that a force is present wherever there is motion, but do not include Aristotle's qualifying statements.

In order to let students see the shortfalls of these ideas it is advisable to allow them to examine the ideas of Aristotle and to let them see the weaknesses of such a system, before explaining how Newton's laws overcome these problems.

Newton's First Law - Exercises

To fully realise the significance of Newton's laws it is useful to know what they replaced. Before Newton, Aristotle's laws had been widely held. They seemed plausible to people then and even today many people still think in the same way. By comparing the two systems you should be able to see some of the shortcomings of Aristotle's laws.

Briefly what Aristotle said was that "The natural state of all objects is at rest" and "Where there is motion there must be a force".

These laws say that if you want something to move you must first pull or push it, and keep on pulling or pushing to keep it moving. If there is no force then it must stop, that is as soon as you stop pushing or pulling it will stop suddenly.

1. Aristotle said that a force was needed for an object to maintain its motion, and that when this is removed the object stops suddenly. Could this argument be used to explain these situations:

(a) A car being pushed on a flat road rolls on for two metres when you stop pushing.

(b) An ice puck slides thirty metres across an ice rink after being hit with a hockey stick.

2. According to Aristotle an object should suddenly stop moving when you stop pushing.

Is this true ?

Give an example to support your answer.

What does cause an object to stop moving ?

3. Suggest reasons why Aristotle thought that the natural state of an object was at rest.

4. This diagram shows the path of a puck on an ice skating rink before it is hit by a stick.

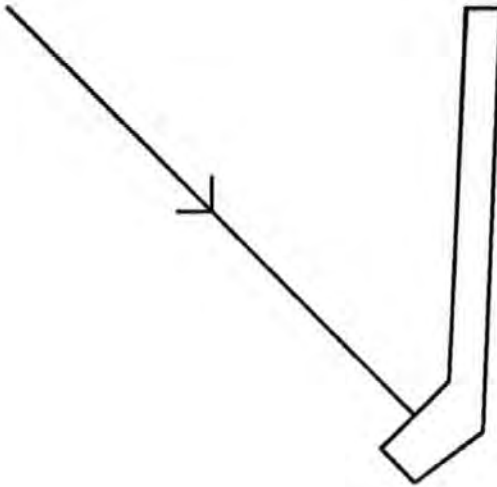


Figure 67 - Diagram for Question 4 of the Newton's First Law Exercises

What can you say about its speed before it is hit by the stick ?

Draw a possible path for it after it has been hit.

What can you say about its speed now ?

When is there a horizontal force acting on the puck ?

If there were no friction when would the puck stop moving ?

Newton's first law says that objects stay at rest or move with uniform velocity, that is at constant speed in a straight line, unless acted on by a force. Our observations of everyday life do not seem to agree with this, as objects slow down and stop moving because of friction. As friction is removed or made less significant, as for example at an ice rink, it is easier to be convinced of the truth of Newton's laws.

5. Ice skaters experience very little friction. Suppose that you push a skater across the ice and then let him glide along the rink. Answer these questions assuming that there is no friction.

- (a) What happens to his speed while you are pushing ?
- (b) What happens to his speed after you stop pushing ?
- (c) Does he move in a straight line ?
- (d) What forces act on the skater after you stop pushing ?

6. A car travelling at 50 mph experiences resistance and frictional forces totalling 700 N. What force must the car's engine exert to keep the car moving with constant velocity ?

7. Do the objects in the following situations have constant velocity. If not explain what force is causing the velocity to change.

- (a) An apple falling from a tree.
- (b) A book resting on a table.
- (c) A parachutist who has reached terminal velocity.
- (d) A train travelling at a steady 65 mph round a very slight bend.

What is a Force ? - Teacher's Notes

1. Summary

The video looks at examples of forces acting and defines four different ways in which a force can change motion. These are that a force is something that can cause a still object to move, stop a moving object, increase or decrease the speed of a moving object and change the direction of motion of an object. These four ideas are then drawn together to define a force as something that causes the motion of an object to change. It then moves on to consider cases where more than one force is present and discusses whether or not the forces are in balance. (Video length 10 minutes).

The exercises examine the forces acting in various situations, identifying them and deciding if they are in equilibrium or not. They also consider briefly the importance of the point of application of the forces.

2. Video Teaching

During the video there are several references to the inertia of an object. It would therefore be advisable to discuss the meaning of inertia before using the video. It could be usefully defined as the tendency of an object to remain still or to move with constant velocity. Centripetal force is also mentioned briefly in connection with an example where the force is changing the direction of motion.

After watching the video further discussion of the examples on the video would be desirable before the students attempt the exercises. In particular it would be interesting to see if any students had noticed the dubious balancing point on the diving board example.

The video uses arrows to represent the forces in its examples, with a bigger arrow for a larger force. It would be good to explain at this stage that a force can be represented by a vector, as it has magnitude and direction. When drawing vectors it should be stressed that they have the same direction as the force and length proportional to the magnitude of the force.

3. Non-Video Teaching

The definition of force should be built up in the same way as in the video, with four examples to show the different ways a force can change motion, then being combined to give the definition of a force.

The four ways in which a force can change motion are;

- (a) To make a still object move, for example if you push a toy car that was stationary it will begin to move.
- (b) To stop a moving object, for example when you catch a ball you exert a force that stops its motion.
- (c) To increase or decrease the speed of a moving object, for example, if you help someone who is pushing a heavy trolley you provide a force that makes it speed up.
- (d) To change the direction of motion of an object, for example, when a snooker ball hits a cushion, the cushion exerts a force that changes the direction of the balls motion.

It is also necessary to discuss forces in equilibrium or balance. Consideration of some examples of situations where forces are both in equilibrium and not in equilibrium will be worthwhile.

Representing forces correctly on diagrams is going to be an important skill if the students are to appreciate fully what is happening in a particular situation. It is therefore important to explain that forces can be represented by vectors, and that these will have both magnitude and direction.

4. Solutions

1. All motion is from left to right.

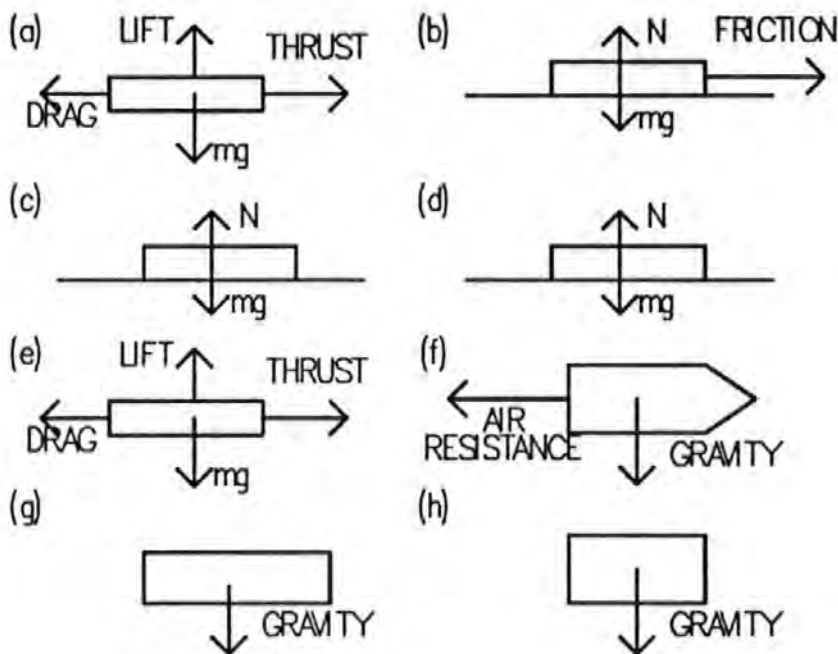


Figure 68 - Solutions for Question 1 of What is a Force Exercises

2. (a) Balanced (b) Unbalanced (c) Balanced, if friction is ignored. (d) Balanced (e) Balanced (f) Unbalanced (g) Unbalanced

3. A The crate turns as it is pushed, pivoting about the right end. B The crate moves forward in a straight line. C The crate turns as it is pushed, pivoting about the left end.

4. (a) A, B and C nothing happens. D the see saw moves. (b) A and B nothing happens. C and D the see saw moves.

5. (a) Yes, if the resistance is equal to the weight. (b) The speed at which the object falls, if this is constant the forces will be in balance.
6. (a) No (b) At all three positions the vectors should be the same, all pointing down.
7. (a) Nothing (b) The lower one goes down and the higher one goes up.

What is a Force ? - Exercises

In these exercises use vectors to represent forces on your diagrams, they should point in the direction that the force acts and their lengths should be proportional to the size of the force.

1. For each of the situations listed below, draw a diagram and show all the forces acting on the object, stating what causes each force:

(a) A hovercraft as it moves across a smooth sea at constant speed in a straight line.

(b) A box in the back of a lorry as it picks up speed along a straight, level motorway.

(c) An ice hockey puck sliding across an ice rink.

(d) A book resting on a table.

(e) An aeroplane flying at constant speed in a straight line, but losing height at a constant rate.

(f) A bullet fired horizontally at high speed from a gun, after it has left the barrel.

(g) A satellite in orbit around the earth.

(h) An astronaut floating freely, a distance away from his spacecraft, which is in orbit around the earth.

2. In which of the above situations are the forces balanced (in equilibrium) ?

3. A large heavy crate lies on the ground. The diagram is looking down on the crate. Describe what happens if you push at each of the points A, B and C as shown.

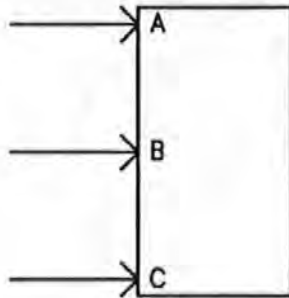


Figure 69 - Diagram for Question 3 of What is a Force Exercises

4. A child sits on one end of a see-saw. His friend, who has the same mass, climbs onto the see-saw and sits in each of the positions A, B, C and D.

(a) What happens at each of these positions ?

(b) What happens if he leans back in each position ?

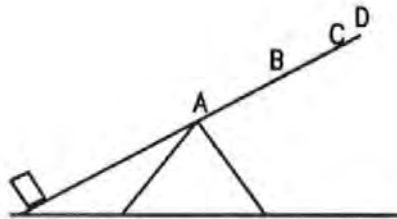


Figure 70 - Diagram for Question 4 of What is a Force Exercises

5. In a science experiment a small object is dropped into a cylinder of oil. Two students watch the object fall, then one of them announces that the forces on the object must be in balance.

(a) Could this be possible ?

(b) What observation would be necessary to decide ?

6. A ball is thrown up in the air. On the diagram at A it is on the way up, at B it is at its highest point and at C on its way down.

(a) Are the forces on the ball ever in equilibrium ?

(b) At each point draw vectors to represent the forces on the ball ?

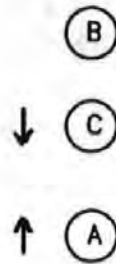


Figure 71 - Diagram for Question 6 of What is a Force ? Exercises

7. Two identical objects of equal mass are connected by a string that passes over a pulley. They are held in the positions shown in the diagram and then released.

(a) What happens if the weight of the string is ignored ?

(b) What happens if the weight of the string is significant ?

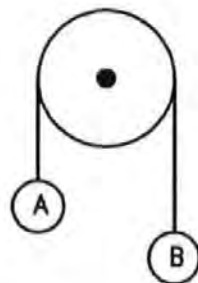


Figure 72 - Diagram for Question 7 of What is a Force Exercises

F=ma : Newton's Second Law - Teacher's Notes

1. Summary

This video sequence introduces Newton's second law and utilizes experimental work in the studio to explore the relationship between force, mass and acceleration. Having stated and verified Newton's law, it is then used to predict the acceleration that will result when a particular force is applied.

The introductory sheet is to encourage students to begin to think about the relationships between mass, force and acceleration, before they consider Newton's second law. It also revises the relationships between displacement, velocity and acceleration that are needed in the video and for the exercises.

The exercises first compare Newton's laws with Aristotle's statement that force is proportional to velocity. The second law is then used in one dimension.

2. Video Teaching

This particular video is somewhat long and repetitive, so it would be unwise to use it in its entirety. A good point to stop may be after the experiment to find the mass of a glider. The amount of this video that is used will depend on the teacher and the group of students.

Students should be able to use the exercises after watching the video. It may be interesting to hold a class discussion on the difference between Aristotle's and Newton's laws of motion.

The second time that the acceleration of a glider needs to be calculated on the video, it is left as an exercise for the student. The value of this acceleration is given as 0.4 m/s^2 . So that the students can confirm this value the table below gives the distance travelled by the glider in the experiment. The calculation should follow the same procedure used on the video of drawing a graph of distance against time, finding the velocity at intervals from the gradient of a tangent, plotting a graph of velocity against time and then finding the acceleration from the gradient of this graph.

Time (s)	0.00	0.75	1.50	2.25	3.00
Distance (m)	0.00	0.12	0.42	0.98	1.64

Table 131 - Data for the Motion of the Glider on the Video

3. Non-Video Teaching

This should concentrate on justifying the use of the second law and illustrating its application. It would be worth comparing Newton's laws with Aristotle's ideas.

The introductory sheet should be used first to encourage students to consider how acceleration and motion are related, and to begin to think about the effects on motion of force and mass. An introduction to Newton's second law can then be followed by the use of the exercises.

4. Solutions - Introduction

1. (a) D (b) E (c) A
2. (a) B (b) E (c) C

3. Acceleration = 5
4. (a) The light one. (b) Yes (c) Yes
5. (a) Slower (b) Yes (c) Yes
6. Size of the force and mass of the object.

5. Solutions - Exercises

1. Constant velocity, No, Increases.
2. (a) Increases (b) No, he would say constant velocity. (c) Constant
3. 35 N
4. 1.5 m/s^2
5. 62.5 tonnes
6. (a) 3-4 seconds freewheeling, starts between 3rd and 4th seconds, ends between 7th and 8th seconds. (b) 2.5
7. (a) 1.15 N (b) 1 N (c) 0.85 N (d) 1 N
8. Mass is reduced, therefore less force will produce the same acceleration, making it easier to push.
9. (a) Between 2 and 3 seconds. (b) 1300 N
- 10.

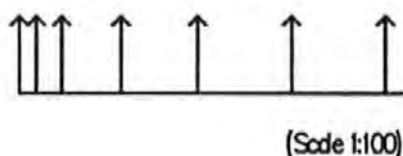


Figure 73 - Solution for Question 10 of Newton's Second Law Exercises

Newton's Second Law - Introduction

1. A car moves away from a set of traffic lights picking up speed until it has to slow down and stop at a second set. For this car which of the graphs below best represents:

- (a) a distance-time graph ?
- (b) a velocity-time graph ?
- (c) an acceleration-time graph ?

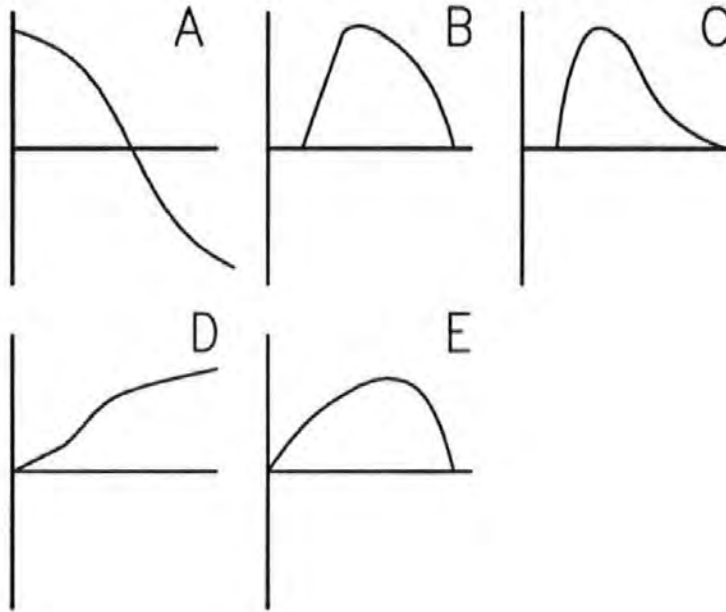


Figure 74 - Graphs for Question 1 of Newton's Second Law Introduction

2. In a game of cricket a batsman scores two runs from one ball. For this batsman which of the graphs below best represents:

- (a) a distance-time graph ?
- (b) a velocity-time graph ?
- (c) an acceleration-time graph ?

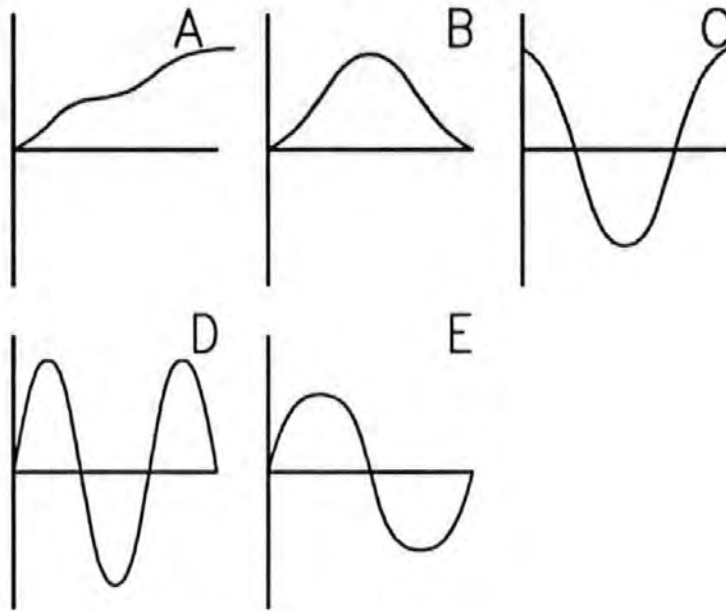


Figure 75 - Graphs for Question 2 of Newton's Second Law Introduction

3. The diagram below shows the positions of a dragster at one second intervals after a standing start.

(a) Draw a distance-time graph for its motion.

(b) Draw a velocity-time graph for its motion.

(c) Use the last graph to calculate its acceleration.

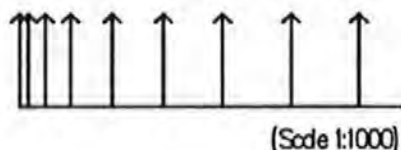


Figure 76 - Diagram for Question 3 of Newton's Second Law Introduction

We have already seen that Newton's first law states that an object will remain in uniform motion unless acted on by a force. Newton's second law explains what happens when a force is applied to an object. We will first think about the law in terms of straight line motion.

4. Imagine that you are having to push a car on a level road. If you have ever had to push a car you may find it helpful to consider this experience.

(a) Would it be easier to push a light car, such as mini, or a heavy car, such as a large estate ?

(b) Is it easier to get the car to speed up if two of you push ?

5. A catapult is used to fire stones. The elastic exerts a force on the stone for a short time while it is being fired, so the stone speeds up while the force is acting and then leaves the catapult with a certain speed.

(a) Will a heavier stone speed up more quickly or more slowly than a light stone?

(b) If a another catapult that exerts a greater force is used will the stones speed up more quickly ?

(c) Is it possible for the more powerful catapult to speed up the larger stone at the same rate as the original one speeds up the smaller stone ?

6. What two factors do you think are important in determining how an object will speed up when acted on by a force ?

F=ma: Newton's Second Law - Exercises

We have already seen that Aristotle's first statement about motion was incorrect. We will now compare his second statement that "Force is proportional to velocity" with Newton's second law ($F=ma$), that force is proportional to acceleration.

1. If a car's engine exerts a constant force, what would Aristotle say about its velocity ?

Is this true ?

What does happen to the velocity of a car if the engine exerts a constant force ?

2. Consider an air puck that hovers on a smooth glass table, so that it does not experience friction as it moves. If a constant force is applied to the puck,

(a) what happens to its velocity ?

(b) does this agree with Aristotle ?

(c) what happens to its velocity if the force is removed ?

Even though he was incorrect, many students today still think in the same way as Aristotle. This is usually because they do not consider all the forces acting on an object, ignoring the friction to make Aristotle's ideas appear true. Use Newton's laws to answer the following questions.

3. What force is required to make an ice skater of mass 70 kg accelerate at 0.5 m/s^2 ?

4. The engine of a car, of mass 1 tonne, provides a force of 2000 N. If there are resistance forces totalling 500 N, what is the acceleration of the car ?

5. A force of 500000 N causes an aeroplane to accelerate at 8 m/s^2 . What is the mass of the plane ?

6. The diagram below shows the position of a bicycle and its rider at one second intervals, as they set off along a level road. Assume that there is no resistance to the motion of the bike.

(a) For a short time the rider stopped pedalling and let the bike freewheel. For how long did it freewheel and when ?

(b) Initially the rider exerts a force of 200 N. If the mass of the rider and the bike is 80 kg, what is the acceleration of the bike at this time?

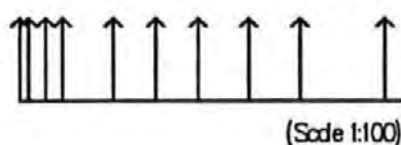


Figure 77 - Diagram for Question 6 of Newton's Second Law Exercises

7. The diagram shows a glider of mass 1.5 kg on a sloping air track. The glider hovers on the track and experiences almost no friction. Gravity exerts a force of 1 N down the track as indicated. The other force, F , up the track can be varied.

What should be the size of the force F if the glider is to;

- (a) move uphill with an acceleration of 0.1 m/s^2 .
- (b) move downhill with a constant speed of 0.2 m/s .
- (c) move downhill with an acceleration of 0.1 m/s^2 .
- (d) remain stationary.

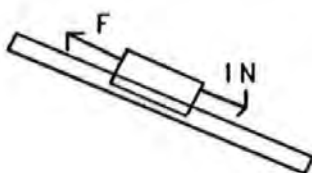


Figure 78 - Diagram for Question 7 of Newton's Second Law Exercises

8. Two men are trying to push a car. Using Newton's second law explain why it is easier to push if the passengers get out and watch.

9. The diagram below shows the positions of a car, at one second intervals, as it approaches a set of red traffic lights.

(a) For how long did the driver apply the brakes before stopping?

(b) The mass of the car is 1200 kg and resistance forces totalling 500 N are present while it is moving. If the acceleration while it is stopping is -1.5 m/s^2 , what force did the brakes exert on the car?

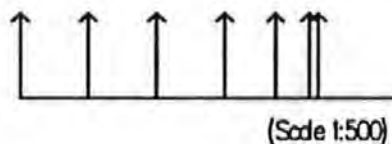


Figure 79 - Diagram for Question 9 of Newton's Second Law Exercises

10. A car of mass 1000 kg travels along a level road and experiences resistance forces totalling 500 N while it is moving. Initially it is stationary, the engine then exerts a force of 1500N for 4 seconds after which it is reduced to 500 N. Draw a diagram similar to the one in question 9 for this car.

Action and Reaction - Teacher's Notes

1. Summary

The video initially uses experiments with springs to demonstrate that all objects exert a reaction force equal to any applied force. Three situations are presented and the students get the chance to predict what will happen, if the video is stopped. An optical technique, that makes clear the presence of forces, is then used to demonstrate further the presence of pairs of action - reaction forces in plastic blocks. First when pulled by a string and secondly when two blocks come into contact. Finally the video considers some everyday situations where action - reaction pairs of forces can be found. It finishes with a problem to find the easiest way to stretch a spring. (Video length 15 minutes).

The exercises initially involve the identification of pairs of action - reaction forces in various situations. Later questions require the use of Newton's third law for their solution.

2. Video Teaching

During the video there are three points where it would be useful to stop and obtain the opinion of the students on what will happen. These are just before the experiments with the spring attached to the flexible plastic strip and the solid plastic block. Also at the end of the video when the problem of finding the easiest way to stretch a spring is introduced. At the end of the video it will be necessary to identify the law of action and reaction as stated in the video as Newton's third law.

3. Non-Video Teaching

This should concentrate on the statement of Newton's third law, using examples that will illustrate that each object exerts a force on the other. Working through the three examples below will help students to see that pairs of action and reaction forces do exist.

(a) Initially consider the extension of a spring that has equal masses attached to each end by pieces of string, as shown in the diagram below. It is obvious that both masses exert equal but opposite forces on each end of the spring.

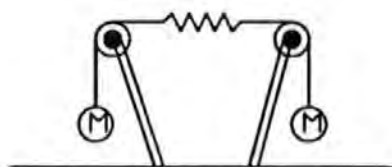


Figure 80 - Apparatus for Non-Video Approach to Action and Reaction Part (a)

(b) Secondly consider what happens when one end of the spring is attached to a flexible plastic strip, as below. How does the extension of the spring compare with what it was in the above situation ?

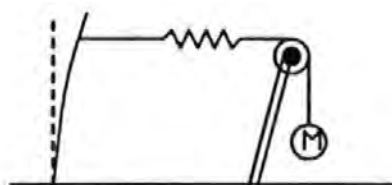


Figure 81 - Apparatus for Non-Video Approach to Action and Reaction Part (b)

The extension is in fact the same, indicating that the strip exerts a force on the spring equal to that exerted by the mass in the first example.

(c) Finally replace the flexible strip by a rigid block, as below. How does the extension of the spring now compare with the original case ?

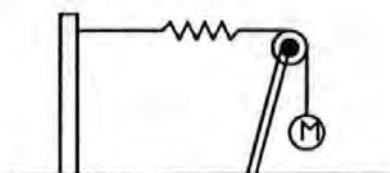


Figure 82 - Apparatus for Non-Video Approach to Action and Reaction Part (c)

It is again the same as in the original case, indicating that the block exerts a force on the spring equal to that exerted by the mass in the first example. Here it is clear that the spring exerts a force on the block equal to the weight of the mass used, but the extension of the spring indicates that the block exerts a force of equal magnitude but opposite direction on the spring. This type of force should be identified as a reaction force.

4. Solutions

1.

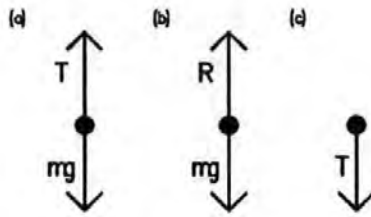


Figure 83 - Solutions to Question 1 for Action and Reaction Exercise

2.

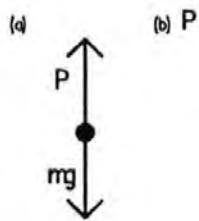


Figure 84 - Solutions to Question 2 for Action and Reaction Exercise

3.

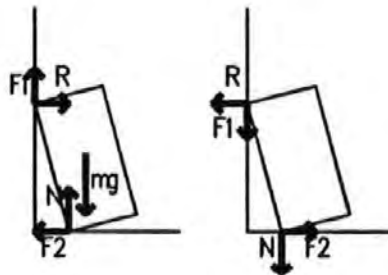


Figure 85 - Solutions to Question 3 For Action and Reaction Exercise

4.

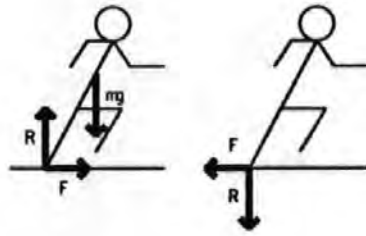


Figure 86 - Solutions to Question 4 For Action and Reaction Exercise

5. 322 N

6.

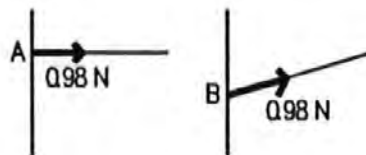


Figure 87 - Solutions to Question 6 For Action and Reaction Exercise

7. As the car exerts a force on the wall this damage the wall. However the wall also exerts an equal but opposite force on the car, which damages the car.

8.

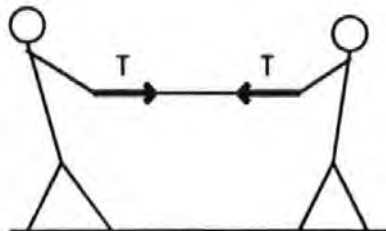


Figure 88 - Solutions to Question 8 For Action and Reaction Exercise

9. (a) 0.43 m/s^2 and 0.6 m/s^2 (b) 0.21 m/s^2 and 0.3 m/s^2

10.(a) $T - 5g$ and $T - 7g$ (b) $(T - 5g)/5$ and $(T - 7g)/7$ (c) 57 N

11. 4.5 m/s^2

12. 0.003 m/s^2 and 0.19 m/s^2

Action and Reaction - Exercises

1. A child is hanging on a rope tied to a branch of a tree. Draw diagrams to show;

- (a) the forces acting on the child,
- (b) the forces on the rope,
- (c) the force that the rope exerts on the branch.

2. The diagram shows a box leaning against a wall. On a copy of the diagram indicate all the forces acting on the crate. On a second diagram indicate all the forces that the box exerts on the ground and the wall.



Figure 89 - Diagram for Question 2 of the Action and Reaction Exercise

3. While a bouncing ball is in contact with the ground there is a short time when the ground exerts force of magnitude P on the ball.

- (a) Draw a diagram to show the forces acting on the ball.
- (b) What force does the ball exert on the ground ?

4. While running an athlete has one foot in contact with the ground. Use two copies of the diagram to show the forces acting;

(a) on the athlete,

(b) on the ground.



Figure 90 - Diagram for Question 4 for Action and Reaction Exercise

5. A tow truck pulls a car of mass 1050 kg so that it overcomes resistance forces of 60 N and accelerates at 0.25 m/s². What force does the car exert on the truck ?

6. The diagram shows a 100 g mass on a piece of string that passes over a pulley. The string is attached to the wall at A or B. What force does the wall exert on the string at each of these positions ?

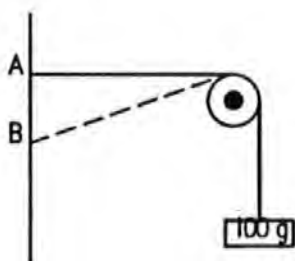


Figure 91 - Diagram for Question 6 of the Action and Reaction Exercise

7. Use Newton's third law to explain why when a car hits a wall both the car and the wall are damaged.

8. Two men are involved in a tug of war competition and the man on the left is winning. On the diagram draw vectors to represent the forces that the rope is exerting on each man.

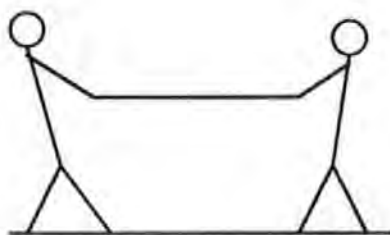


Figure 92 - Diagram for Question 8 of the Action and Reaction Exercise

9. Two ice skaters stand next to each other on an ice skating rink, one is of mass 70 kg and the other of mass 50 kg. The smaller one exerts a force of 30 N on the larger one, for a period of half a second.

(a) What are the accelerations of both skaters during the first half second ?

(b) What are the speeds of the two skaters at the end of the half second ?

10. Two blocks are connected by a string passing over a pulley as shown in the diagram. One is of mass 7 kg and the other 5 kg, and are released from the position shown. Just after release the tension in the string is T .

(a) What is the resultant force on each block at this time (in terms of T) ?

(b) What is the acceleration of each block at this time ?

(c) Both these accelerations must be equal in magnitude but opposite in direction, since one is accelerating upwards and the other downwards. Use this to find the tension in the string.

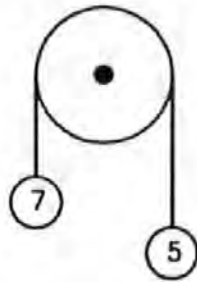


Figure 93 - Diagram for Question 10 of the Action and Reaction Exercise

11. Calculate the acceleration of this system if it is released. The blocks of mass 7 kg and 6 kg are connected by a light string passing over a pulley. Assume that there is no friction.

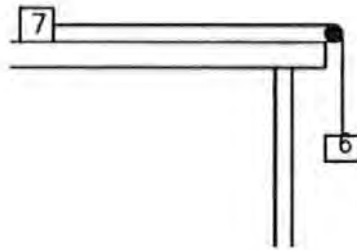


Figure 94 - Diagram for Question 11 of the Action and Reaction Exercise

12. An astronaut is attached to a spaceship by a cable, he pulls on the cable, exerting a force of 15 N. If the mass of the spaceship is 5000 kg and the astronaut 79kg, what are their resulting accelerations ?

Introduction to Momentum - Teacher's Notes

1. Summary

The video first looks at situations in which momentum changes take place, in the real world. It then explores the role that mass and velocity play in making up the momentum of an object. Initially this is done qualitatively, by looking at how easy it is to knock down a skittle, and then in a controlled experiment using air pucks hovering on a glass table. The fact that momentum is a vector is also included towards the end of the video. (Video length 9 minutes).

The exercises involve the calculation and comparison of the momentum of various objects, and also finding the mass and velocity from a given momentum. A few questions then relate to the vector nature of the concept.

2. Video Teaching

The students should be able to attempt the exercises straight after watching the video. The only point that needs additional emphasis is that momentum is a vector quantity. Teachers may feel that some class discussion of points and examples on the video is valuable.

3. Non-Video Teaching

This should include the defining of momentum as the product of mass and velocity, and that it is a vector quantity. It will be useful to discuss the role that momentum plays in predicting how difficult it would be to knock over an obstruction, perhaps referring to the damage in car accidents.

4. Solutions

1. 6 kgm/s
2. The heavier one.
3. 8.6 m/s
4. 1.9 kg
5. 2.7 kgm/s at an angle of 45° to the horizontal, or $1.9\mathbf{i} + 1.9\mathbf{j}$
6. Magnitude constant, but direction changing, therefore variable.
- 7.

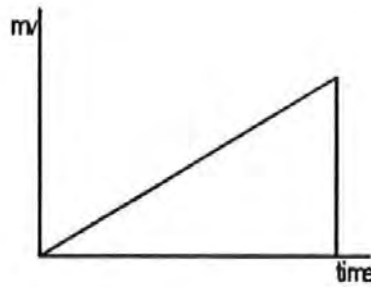


Figure 95 - Diagram for Question 7 of Introduction to Momentum

8. 1.8 m/s
9. Momentum before = $0.065\mathbf{i} + -0.038\mathbf{j}$ Momentum after = $0.057\mathbf{i} + 0.036\mathbf{j}$
Momentum change = $-0.008\mathbf{i} + 0.074\mathbf{j}$

Introduction to Momentum - Exercises

1. A football of mass 1.5 kg is headed into a goal. When it hits the back of the net it has a speed of 4 m/s, find the magnitude of the momentum that the ball must give up to stop.
2. Two roller skaters have masses 76 kg and 68 kg. If the heavier one is moving at 2.8 m/s and the lighter one at 3.1 m/s, which one would be easiest to stop?
3. A wooden skittle is just knocked down by a heavy wooden ball of mass 3 kg moving at 2.3 m/s. At what speed would a lighter ball of mass 0.8 kg have to move if it is to knock the skittle down? Is this a reasonable speed?
4. This diagram shows the positions of two air pucks exactly two seconds after they started moving with constant speeds. If they have the same momentum, what is the mass of the slower puck?

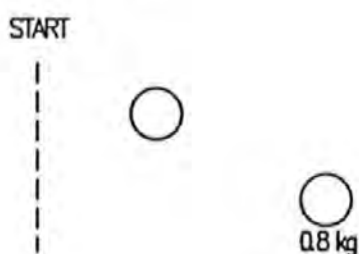


Figure 96 - Diagram for Question 4 of Introduction to Momentum

5. A golf ball of mass 0.045 kg is hit and has an initial velocity of 60 m/s at 45° to the horizontal. Find the momentum just after it has been hit, expressing it in terms of the unit vectors \mathbf{i} and \mathbf{j} .

6. A car drives along a winding road at a steady 40 km/hr. What can you say about its momentum? Estimate the magnitude of its momentum.

7. An egg is dropped from a height of about one metre and falls to the floor where it smashes. Sketch a graph of the magnitude of momentum against time for the egg while it is falling.

8. Two railway wagons are given equal amounts of momentum. The mass of the small wagon is 6 tonnes and it has a speed of 3 m/s. What will be the speed of the larger wagon if it has a mass of 10 tonnes ?

9. A snooker ball, of mass 250g, hits a cushion at an angle of 30° when it had speed 0.3 m/s. After bouncing it has a velocity of 0.27 m/s at an angle of 32° to the cushion. If the unit vector \mathbf{i} is parallel to the side cushion and the unit vector \mathbf{j} is perpendicular to it.

(a) Calculate the momentum of the ball just before it hits the cushion and just after.

(b) What is the change in momentum ($m\mathbf{v} - m\mathbf{u}$) ?

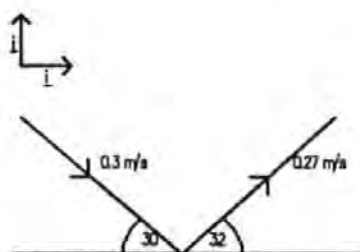


Figure 97 - Diagram for Question 9 of Introduction to Momentum

10. Select some examples of momentum changes you have seen in real life situations. Describe them and estimate the change in momentum.

Parabolic Path of a Projectile - Teacher's Notes

1. Summary

The video begins by looking at the path of a shot from the moment that it is released by the shot putter. An air table in the studio is used to simulate the motion in a controlled way and at a much slower pace. It is shown that the shot follows a parabolic path. The presenter gives the equations that describe the acceleration of the shot, states the equation of the path derived from them and that this can be rearranged to give the equation of a parabola. The presence of an acceleration in the vertical component of the motion and the absence of an acceleration in the horizontal component of motion are illustrated. (Video length 11 minutes).

The exercises cover a range of problems on projectile motion.

2. Video Teaching

It will be necessary after watching the video to explain how the equations of motion can be obtained by considering the force acting on the particle. This is laid out on a separate sheet.

The video treated the shot as a particle and assumed that the path depended only on the angle and speed of projection. It would be worth discussing these assumptions and the way other factors may influence the path of the shot. Factors such as air resistance, spin and weather conditions may be worth discussion. A more extensive list of factors can be found in the "Visualising Mechanics" booklet.

When doing the exercises it is recommended that the students do not try to use memorised formulae, but build up equations of motion for each question incorporating the initial conditions as they arise.

3. Non-Video Teaching

The treatment of the path of a projectile should begin with the identification of all the factors that influence the motion of the projectile. This will obviously include the identification of the forces acting so that Newton's second law can be applied. It should also include the influence of other factors, such as air resistance, weather conditions and the effects of spin, and the assumptions made about them. A full list of factors that could be considered can be found in the "Visualising Mechanics" booklet.

An additional sheet outlines the solution of the problem, and shows that the path is parabolic. The students will need to consider some examples of projectile motion before attempting the exercises.

When doing the exercises it is recommended that the students do not try to use memorised formulae, but build up equations of motion for each question incorporating the initial conditions as they arise.

4. Solutions

1.

t	0	1	2	3	4	5	6	7	8
x	0	58	115	172	229	287	344	401	459
y	0	35	61	76	82	78	65	41	8

Table 132 - Values of x, y and t for Question 1 of the Path of a Projectile

Exercises

(a) 470 m (b) 8.2 seconds (c) 82 m

2. 1.2 m

3. 1.05 s, $1.2\mathbf{i} - 9.9\mathbf{j}$, 10m/s at an angle of 83° to the horizontal.

4. Yes (70 m range), No, Probably not a good idea.

5. 32

6. $y = 0.7x - 0.018x^2$, 39 m

7. 21.4°

8. (a) Yes (43 m above ground level). (b) 54 m/s

9. $(V \sin a)/2g$

10. $t = (2V \sin a)/g$, $R = (V \sin 2a)/g$

The Parabolic Path of a Projectile

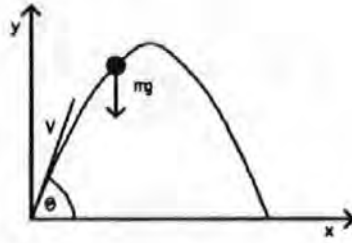


Figure 98 - Diagram for the Parabolic Path of a Projectile

The projectile is launched with velocity of magnitude, V , at an angle, Θ , above the horizontal. After the projectile has been launched the only force acting on it is gravity, assuming that air resistance is negligible.

Therefore the acceleration of the projectile is given by;

$$\underline{a} = 0\mathbf{i} - g\mathbf{j}$$

These can be integrated to find the velocity;

$$\underline{v} = A\mathbf{i} + (C - gt)\mathbf{j}$$

Initially we know that;

$$\underline{v} = V\cos(\Theta)\mathbf{i} + V\sin(\Theta)\mathbf{j}$$

So that we can show that;

$$\underline{v} = V\cos(\Theta)\mathbf{i} + (V\sin(\Theta) - gt)\mathbf{j}$$

Integrating again to find the position vector of the projectile, and assuming that it was launched from the origin gives;

$$\underline{r} = Vt\cos(\Theta)\mathbf{i} + (Vt\sin(\Theta) - 0.5gt^2)\mathbf{j}$$

If we assume that the position vector is of the form;

$$\underline{r} = x\mathbf{i} + y\mathbf{j}$$

To find the equation of the path we need to equate the coefficients in both equations and eliminate t from them.

Rearranging the expression for x gives;

$$t = x/(V\cos(\Theta))$$

This can then be substituted into the expression for y, to give;

$$y = -0.5gx^2/(V\cos(\Theta))^2 + x\tan(\Theta)$$

This expression can be rearranged in the form;

$$y = ax + bx$$

This is of course the equation of a parabola.

Parabolic Path of a Projectile - Exercises

1. A golf ball is projected with initial velocity of 70 m/s at an angle of 35° to the horizontal. By considering the golf ball to be a projectile, calculate the position of the ball at one second intervals for the first eight seconds of its flight. Using suitable scales plot the path of the ball. From this estimate:

(a) The horizontal distance covered between the time the ball is hit and its first bounce.

(b) The time between the hit and the first bounce.

(c) The greatest height of the ball during its flight. On the same diagram draw the parabola with equation: $y = -0.0015x^2 + 0.7x$

Compare this with the path.

2. A bullet is fired horizontally at 300m/s. How much has it dropped by the time it hits a target 150m away ?

3. A diving board is 5m above the level of the water in a pool. If a swimmer dives so that he initially has a velocity of 1.2m/s at an angle of 18° above the horizontal, after how long will he hit the water and what will his velocity be then?

4. A stunt motorcycle rider is going to attempt to jump over a deep river valley 50 m wide. He uses a ramp at 25° to the horizontal for his take off and has a speed of 30 m/s at this time. Will the rider be able to safely cross the gap ? Do you think it is reasonable to ignore air resistance in this case, would you advise the rider to attempt the stunt ?

5. The stunt man in question 4 finds that, due to air resistance he only covers 60% of the distance that he predicts, by considering himself as a particle. If his maximum take off speed is 33 m/s, what is the smallest safe angle for his take off to jump 60m ?

6. A cricket ball is hit so that its initial velocity is 20 m/s at an angle of 35° above the horizontal. Find the equation of the path of the ball, eliminating t to express it in terms of x and y . What horizontal distance has the ball covered when it hits the ground ?

7. A gunner wishes to hit a target 250 m away. If his shells are fired with an initial speed of 60 m/s, what angle of projection should he use ?

8. A golfer wishes to clear a row of trees 25m high. He hits his ball from a spot 200 m in front of the trees. If the angle of projection is 30° ,

(a) Does he clear the trees with an initial velocity of 60 m/s ?

(b) What is the smallest initial velocity that will allow the ball to clear the trees ?

9. Using the equations of motion for a projectile, launched from ground level, and differentiating find an expression for y . This will be zero at the highest point of the flight. Find the time taken to reach this point and its height, in terms of the angle of release, α , the initial speed, V and the acceleration due to gravity, g .

10. Find the total time of flight and hence the range of a projectile in terms of α , V and g , as used in question 9.

The Optimum Angle - Teacher's Notes

1. Summary

The video looks at the problem of achieving the greatest range for a given speed of projection, by finding the optimum angle of projection. This is considered particularly in the context of shot putting as used in the previous section. Expressions for the angle in terms of the range and the range in terms of the angle are derived. These are confirmed by experiments on the air table. The maximum range is shown to be achieved when the angle of projection is 45° , if the projectile is released from ground level. Finally it is shown that the angle for the greatest range is smaller if the height of the shot putter is taken into account.

The exercises include finding the range of projectiles that are not launched from ground level and finding the maximum range for a shot taking account of the height of release.

Two computer programs are provided on a disc. The first "range" will calculate the range for any set of initial conditions. The second "path" will illustrate the paths of up to three projectiles and allow a close look at the landing positions for angles of projection in the range 35° to 50° .

2. Video Teaching

After watching the video students should be able to attempt the exercises. Question 4 could be treated as a group exercise with the calculations shared out around the class and collected to allow the students to draw their own graphs. A computer programme to generate these values and illustrate the paths of projectiles launched with different initial conditions is included.

3. Non-Video Teaching

A derivation of the expression for the range of a projectile is necessary, which can be used to indicate that the maximum range is achieved with an angle of 45° . The problem of the shot putter can then be introduced, and the question of how to achieve the maximum range, when the shot is launched from a non zero height, can be considered. By comparing the ranges of projectiles launched with angles of projection of 45° and 43° , from a height of 1.8 m, it should be possible to see that the second has a greater range. The computer programs provided on the discs will enable students to compare the paths of projectiles, launched with different initial conditions and calculate the range of a projectile.

4. Solutions

1. Increase

2. (a) 14.7 m/s (b) No (greatest height of path is 5.54 m).

3. The second one (ranges of 21.48 m and 21.81 m).

4.(a) (b)

Angle	Range		Speed	Range
35°	21.07		13.0	18.95
36°	22.22		13.1	19.22
37°	21.36		13.2	19.49
38°	21.47		13.3	19.76
39°	21.57		13.4	20.00
40°	21.64		13.5	20.31
41°	21.69		13.6	20.59
42°	21.72		13.7	20.87
43°	21.72		13.8	21.15
44°	21.71		13.9	21.44
45°	21.69		14.0	21.72
46°	21.61		14.1	22.01
47°	21.52		14.2	22.30
48°	21.41		14.3	22.59
49°	21.28		14.4	22.89
50°	21.13		14.5	23.18

Table 133 - Results for Question 4 for the Optimum Angle Exercise

(c) Provided the angle is in the range 41° - 45° the shot putter should concentrate on maximising the speed of release.

The Optimum Angle - Exercises

1. When trying to hit a target a gunner increases or decreases his angle of projection by small amounts until he hits it. With an angle of 55° he finds that the shells are going beyond the target, should he increase or decrease the angle of projection ?

2. At the Seoul Olympics of 1988, U. Timmerman of East Germany established a new Olympic record of 22.47m in the shot put. If the shot was projected at an angle of 45° from ground level :

(a) Calculate the speed of release.

(b) Could this record have been achieved in a sports hall of length 30 m and height 5m.

3. At an athletics meeting there are two favourites in the shot putting event. The first is of height 1.6 m launches a shot at 14m/s at an angle of 45° . His opponent of height 1.9 m launches his shot at the same speed but at an angle of 42° . Which of the two shot putters wins the competition ?

4. For a projectile launched from ground level it is possible to see that the greatest range can be achieved when the angle of projection is 45° . However in reality many objects are not launched from ground level, for example the shot that we have already begun to consider. Assume that a typical shot putter is 1.8 m tall and draw graphs to show how :

(a) The range changes as the angle of projection is varied from 35° to 50° at 1° intervals, with the initial speed fixed at 14m/s.

(b) The range changes as the initial speed is varied from 13 to 14.5 m/s, at 0.1 m/s intervals, with the angle fixed at the optimum from part (a).

(c) From your graphs decide which you think is most critical the angle or the speed of release.

Acceleration at Constant Speed (Circular Motion) - Teacher's Notes

1. Summary

The video begins by looking at ways of detecting the presence of an acceleration, which are used later in the programme. It also points out that acceleration is normally associated with increasing speed. A rotating table is used to show that an object in uniform circular motion experiences an acceleration towards the centre of the circle. The effects of varying the rate of rotation and the radius of the circle are demonstrated. The relationship between this acceleration, the velocity of the object and the radius of the circle, is derived by looking at the change in velocity. Some examples of circular motion are then considered, with the forces that cause the acceleration being identified. Finally the video considers what happens when these forces are removed. (Video length 25 minutes).

The exercises cover a range of problems relating to uniform circular motion. These include ones where angular velocities are used as well as ones using velocity.

2. Video Teaching

As the video does not refer to angular velocity it is important that this is introduced by the teacher. Defining $\omega = \frac{\theta}{t}$ will lead to $v = r\omega$ which can then be substituted into the expression obtained on the video. Changing the units of angular velocity from radians/second to rpm is also important.

3. Non-Video Teaching

The derivation of an expression for the acceleration of an object in uniform circular motion is an essential part of this, and should follow the steps, laid out on a separate sheet, as used in the video. The result should be given as both $a=v^2/r$ and $a=rw^2$. Students must be aware that this is directed towards the centre of the circle. They will also need to be able to change the units of angular velocities from radians/second to rpm. The effects of altering v , w and r should be considered, and also those of removing the force causing the acceleration.

4. Solutions

1. (a) 2.47 m/s^2 (b) Towards the centre of the circle. (c) Friction, the force that the road exerts on the tyres. (d) If the ice totally eliminates the friction between the wheels and the road the car will move along a tangent to the roundabout.

2. 20.6 km

3. (a) 4.7 rad/sec (b) 0.84 m/s

4. 30 rad/sec

5. 5 seconds .

6. 263 N

7. 9.87 m/s^2 , 636 N

8. For A; $a = 1184 \text{ m/s}^2$. For B; $a = 1404 \text{ m/s}^2$. B more efficient.

9. 5.7 N

10. 57 km/hr ($= 15.8 \text{ m/s}$)

11. Nearest the outside

Derivation of the Acceleration of an Object in Circular Motion

The diagram shows a particle moving in a circle. At a particular instant it is at the point A and has a velocity vector $\underline{V}(t)$. A short time Δt later it is at B and has velocity vector $\underline{V}(t+\Delta t)$. Θ is the angle between the two velocity vectors.

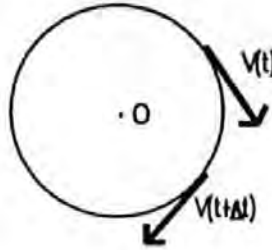


Figure 99 - Diagram showing Velocity Vectors

These two velocity vectors can be repositioned to show $\Delta \underline{V}$, the change in the velocity.

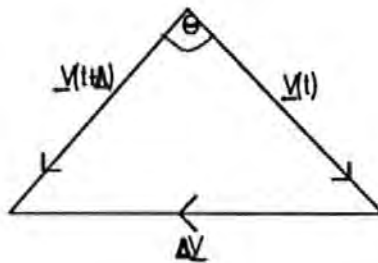


Figure 100 - Diagram Showing Change in Velocity

Since the speed is constant both $\underline{V}(t+\Delta t)$ and $\underline{V}(t)$ have the same magnitude, V . Using trigonometry it can be seen that:

$$\Delta V = 2V\sin(\Theta/2)$$

The time taken for this movement, Δt , can be found by dividing the distance travelled by the velocity:

$$t = r\Theta/V$$

Now the acceleration can be found since;

$$\begin{aligned} a &= \lim_{\Delta t \rightarrow 0} (\Delta v / \Delta t) \\ &= \lim_{\Theta \rightarrow 0} V^2 \sin(\Theta/2) / (r\Theta/2) \\ &= v^2/r \end{aligned}$$

Acceleration at Constant Speed (Circular Motion) - Exercises

1. A car on a roundabout is moving in a circle of radius 50 m at a constant speed of 40 km/hr.

(a) What is its acceleration ?

(b) In what direction is this acceleration ?

(c) What provides the force to cause this acceleration ?

(d) If part of the roundabout is covered with smooth ice, sketch the path of the car when it hits the ice.

2. The pilot of an aeroplane experiences an acceleration of 15 m/s^2 while flying in a horizontal circle at a constant 2000 km/hr. What is the radius of the circle ?

3. A 7" record on a turn-table rotates at 45 rpm.

(a) What is its angular velocity in radians per second ?

(b) What is the velocity of a point on the circumference (7"=17.8 cm) ?

4. A petrol engine is started by winding a rope around a cylinder of radius 4 cm and pulling. If the rope is pulled with a velocity of 1.2 m/s, what is the angular velocity of the cylinder ?

5. The passengers on a fairground ride follow a horizontal circular path of radius 5m and experience an acceleration of 8 m/s^2 . How long does one rotation of the ride take ?

6. A rotary lawn mower uses a piece of light nylon thread with a small particle on the end to cut the grass. The cord is of length 20 cm and the mass of the particle is 30 grams. What is the greatest force that the thread must exert on the particle if the maximum rate of rotation is 2000 rpm.

7. A space station of radius 25 m rotates at 6 rpm, to create artificial gravity. What acceleration does an object on the floor of the space station experience ? An astronaut is resting on his bunk 2m above the floor of the space station. If his mass is 70 kg, what force does the bunk exert on him ?

8. Two spin driers, that both rotate about a vertical axis, have different specifications as given in the table below:

Model	Rate Of Rotation	Drum Diameter
A	600 rpm	60 cm
B	800 rpm	40 cm

Table 134 - Data on Washing Machines

By considering the acceleration of an object at the edge of each drum, decide which will be the most efficient.

9. A child's toy consists of a model aeroplane, of mass 180 grams, on the end of a piece of string 80cm long. The child swings the aeroplane around in a horizontal circle on the end of the string. Research has shown that the fastest that children can swing the plane round is at one revolution per second. What is the greatest force that the string must be able to withstand ?

10. A slip road from a motorway is circular with radius 50 m. The greatest frictional force that the road can exert on a car of mass 1000 kg is 5000 N. Assuming that the car travels at a constant speed and that there is no air resistance, what is the maximum speed at which the car can safely use the slip road.

11. Two children visiting a fairground want to experience the greatest possible acceleration on each ride. A particular ride has seats at varying distances from the centre of rotation. Where should they sit ?

Dynamic Analysis - Teacher's Notes

1. Summary

This video takes and solves two engineering problems, firstly to find the force on a gudgeon pin in a petrol engine and secondly to find the minimum safe rate of rotation for a fairground ride. The video sets out the problems in detail and revises Newton's laws before solving the problems. The presenters work through a series of problem solving steps to arrive at a solution. For the fairground ride a model is used to demonstrate the validity of the results. (Video length 25 minutes).

The exercises cover a range of problems involving motion in a vertical circle. The first few limit themselves to considering the highest and lowest points of the circle while later questions also include other points. Throughout this section the rate of rotation is kept constant, so that there is no need to consider energy.

2. Video Teaching

The two examples used in the video relate to the circular motion of a fairground ride and the motion of a linkage in a petrol engine. The kinematic constraint for circular motion will be familiar to the students, but the one for the linkage will need to be justified or derived. A derivation of this result is included on a separate sheet. It is best to place most emphasis on the fairground ride when discussing the video.

As the video only considers the highest point of the circle it will be necessary to look at other points, probably the lowest point and a point elsewhere on the circumference. The procedure of finding the radial components of the forces

acting and equating them to $mr\omega^2$ or mv^2/r as appropriate, should be used for solving problems.

3. Non-Video Teaching

This should consider the forces acting on a particle at various points on a vertical circle. As with the video teaching it would be useful to establish the procedure of examining the radial components of force and equating them to $mr\omega^2$ or mv^2/r as appropriate. It is probably best to consider the top and bottom points of the circle first and then move to other points on the circumference. The fact that a force causing a suitable acceleration must be present if circular motion is to take place must be stressed, and the consequences of not meeting this criterion explained.

It would be good to work through the analysis for the model fairground ride, which is included on a separate sheet. However the petrol engine example is less suitable for a study without video.

4. Solutions

1. 6.3 m/s or 22.5 km/hr, falls away before reaching the top.
2. 7.9N at bottom and 6.9N at the top.
3. 158000 N
4. 44 rpm
5. (a) Yes (b) 54 km/hr(15.2 m/s)

Additional Notes for Dynamic Analysis

1. Details of the Model Fairground Ride

The ride consists of a cylinder that rotates about its axis of symmetry. The ride rotates in a horizontal circle until it picks up speed, and the riders appear to be stuck to the sides. It then maintains the same rate of rotation but is moved to a vertical position. The analysis is made in this position to find the minimum safe rate of rotation.

The model is of radius 20 cm and the assumption is made that at the top of the ride gravity is the only force acting on the rider. Hence;

$$mg = mrw^2$$

and so

$$w^2 = g/r$$

Substitution of the value of the radius gives the required value for w .

2. Derivation of the Acceleration of a Piston at T.D.C.

The piston P is attached by the connecting rod, of length l , to a point C on the crankshaft. This point C moves in a circle of radius r with angular velocity w . The diagram below illustrates this situation.

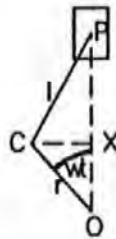


Figure 101 - Diagram Showing the Displacement of the Piston

The distances OX and XP can be calculated using trigonometry and Pythagoras' theorem. Since the piston only moves vertically it is only necessary to consider this component of its acceleration (all others being zero).

The displacement of P from O at any instant is given by:

$$x = r\cos(wt) + (l^2 - r^2\sin^2(wt))^{0.5}$$

The velocity of P is then found by differentiating and the acceleration of P is then found by differentiating again when $t=0$ this becomes:

$$a = -rw^2(1+r)/l$$

Dynamic Analysis - Exercises

1. An motorcyclist performs a loop the loop stunt, by riding at high speed inside a track consisting of a cylinder of radius 4 m. Throughout the stunt the rider ensures that the motorbike maintains a constant speed. Calculate the minimum speed at which the stunt should be performed. What happens if the rider attempts the stunt at a slower speed ? At what point does the cylinder exert the greatest force on the motorbike ?
2. A conker of mass 50 g is swung round and round in a vertical circle of radius 60 cm with a constant rate of rotation of 150 rpm. What are the greatest and least tensions in the string and when do they occur ?
3. As an aeroplane, of mass 2500 kg, pulls out of a dive at 200 m/s its path is a vertical circle with radius 750 m. What lift force must the aeroplane provide at the lowest point of the dive ?

4. To be most effective the clothes in a tumble drier should not always stick to the side of the drier. A designer considers that ideally the clothes should fall away from the side of the drier when in the position shown in the diagram below, at an angle of 30° to the vertical. Calculate the speed of rotation for a drier with a drum of diameter 80 cm to allow the clothes to fall away from the side in this position.

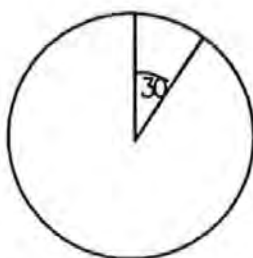


Figure 102 - Diagram for Question 4 of Dynamic Analysis

5. The top of a humpback bridge is circular and is approached by steep straight roads. The radius of the circle is 25 m and the arc has an angle of 40° , as shown in the diagram.

- (a) Can a car travelling at a constant 50 km/hr cross the bridge without leaving the road ?
- (b) What is the maximum safe crossing speed for the bridge ?

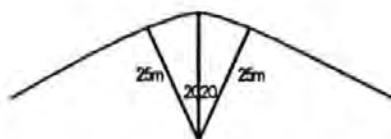


Figure 103 - Diagram for Question 5 of Dynamic Analysis Exercises

Appendix C - The Tests and Questionnaires Used in the Experiment

This appendix contains copies of all the test questions and questionnaires used in the experiment at Exeter College.

1 Pre-Test Questions Used in Year One of the Experiment

1. A spaceship is stationary deep in space. It fires its engines for two minutes and then turns them off.

(i) How does the speed of the rocket change during this two minute period ?

(ii) What happens to the motion of the spaceship after this period, when the engines are turned off ?

(iii) On the axes below sketch a graph of speed against time for the motion of the spaceship.

(iv) An identical spaceship that is carrying a heavy load fires its engines in exactly the same way. How does its motion compare with the original one ?

Also sketch a graph of speed against time for this graph spaceship on the same set of axes. Clearly label each graph that you draw.

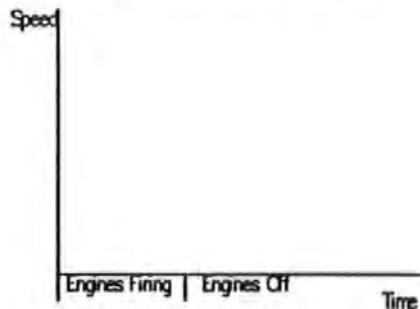


Figure 104 - Diagram for Question 1 of the Year One Pre-Test

2. Which of the following is most likely to break a window ?

A - A 500 g ball moving at 2 m/s

B - A 300 g ball moving at 4 m/s

C - A 100 g ball moving at 9 m/s

Why did you choose this one ?

3. You and a friend, who is the same size and mass as you, are standing still facing each other on roller skates. If you push your friend what happens;

- (i) to you ?
- (ii) to your friend ?

4. A small ball is fired into the tube shown at high speed. The tube has very smooth sides and lies on a horizontal, smooth table. The diagram shows the tube viewed from above as it lies flat on the table.

- (i) Draw the path of the ball after it leaves the tube.
- (ii) If the speed of the ball is constant describe what happens to the velocity of the ball while it is in the tube.
- (iii) Describe what happens to the velocity of the ball after it leaves the tube ?

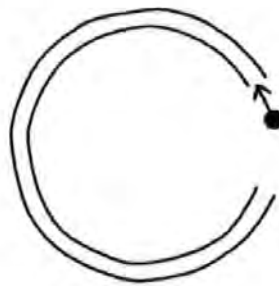


Figure 105 - Diagram for Question 4 of the Year One Pre-Test

5. A heavy book is dropped onto a set of bathroom scales. Describe what happens to the reading on the scales.

6. A cricket ball is thrown into the air with an initial velocity shown by the arrow on the diagram.

(i) Sketch a possible path of the ball, from the point O where it is launched to the point where it bounces for the first time.

(ii) If you were to decrease the angle Θ without altering the magnitude of the velocity, what would happen to the horizontal distance travelled by the ball ?



Figure 106 - Diagram for Question 6 of the Year One Pre-Test

7. As a motorcycle goes round a roundabout its speed remains constant. What happens to its acceleration ?

8. On a bombing run a plane approaches its target along a straight line at constant speed. If the plane maintains this course where is it when the bombs hit the target ?

9. Two balls are exactly the same size and shape, but have masses of 1 kg and 3 kg. They are dropped at the same time from the same height.

(i) How does the time that they take to fall to the ground compare?

(ii) If this experiment were repeated on the moon, how would the results compare ?

10. A cyclist is riding along a straight road at constant speed, when a coin falls out of his pocket. Where does the coin hit the ground relative to the cyclist ?

11. The diagram is looking down on a ball on the end of a piece of string that is being swung round in a horizontal circle at fairly high speed. On the diagram draw the path of the ball if the string breaks at the point marked X.



Figure 107 - Diagram for Question 11 of the Year One Pre-Test

12. A girl dives off a boat into a lake with a velocity that is initially horizontal. What happens just after she loses contact with the boat;

- (i) to the girl ?
- (ii) to the boat ?

13. Deep in space away from any planets an astronaut throws a small object.

- (i) Describe how it moves after it has been released ?
- (ii) When does it stop moving ?

14. A large catapult is used to launch stones. Will a light stone or a heavy stone stay in contact with the catapult for longest during firing ?

15. A ball is thrown vertically, up in the air, as shown in the diagram. At A it is on its way up, at B it is at its highest point and at C it is on its way down.

(i) Draw arrows to show the direction of the acceleration at each of these three points ?

(ii) How does the magnitude of the acceleration of the ball compare at each of these three points ?

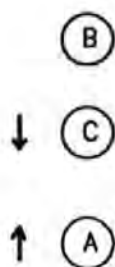


Figure 108 - Diagram for Question 15 of the Year One Pre-Test

16. When a jet of water is fired at a model boat on a pond it begins to move. If the same jet is fired at a heavier boat that is the same size, how will its speed compare with the original one, 5 seconds after the jet was turned on ? Why ?

17. A motorbike is overtaking a car on a motorway. How do the speeds of the two vehicles compare at the instant that they are level ?

18. A horse starts pulling a cart that moves with very little resistance to motion. Another identical cart pulled by two horses begins to move at the same time. If all the horses are pulling as hard as they can how will the speeds of the two carts compare

(i) after thirty seconds ?

(ii) after they have moved fifty metres ?

19. A bag of sugar is placed on a set of kitchen scales (a spring balance), which shows a reading of 1 kg. What reading would it show if it were;

(i) dropped out of an aeroplane, while it is falling ?

(ii) on the moon ?

20. An object is resting on a smooth level surface when you start pushing it. What happens to its velocity if you keep pushing it as hard as you can in a straight line ?

21. Two identical guns that are positioned side by side are aiming at the same target. Their operators calculate very different angles to fire their guns at, is it possible for them both to hit the target ? Explain why you have given this answer.

22. A conker on the end of a piece of string is swung round in a vertical circle at a constant rate.

(i) At which point on the circle is the string most likely to break ?

(ii) If a shorter piece of string were used at the same rate of rotation, would it be more or less likely to break ?

(iii) If a longer piece of string were used, would it be more or less likely to break?

23. A football is rolling along the dotted line shown in the diagram. When it gets to the point X it is kicked by a boot that moves in the direction shown by the solid arrow. Draw the path of the ball after it has been kicked, if the diagram shows the motion of the ball viewed from above.

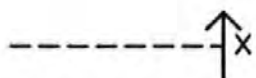


Figure 109 - Diagram for Question 23 of the Year One Pre-Test

2 Pre-Test Questions Used in Year Two of the Experiment

1. A spaceship is stationary deep in space. It fires its engines for two minutes and then turns them off.

(i) How does the speed of the rocket change during this two minute period ?

(ii) What happens to the motion of the spaceship after this period, when the engines are turned off ?

(iii) On the axes below sketch a graph of speed against time for the motion of the spaceship.

(iv) An identical spaceship that is carrying a heavy load fires its engines in exactly the same way. Sketch a graph of speed against time for this graph spaceship on the same set of axes. Clearly label each graph that you draw.

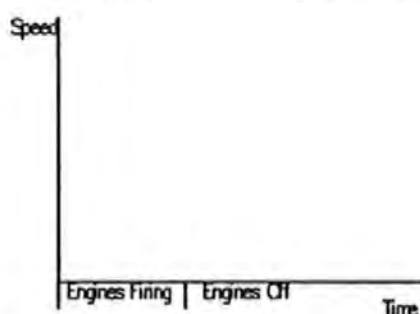


Figure 110 - Diagram for Question 1 of the Year Two Pre-Test

2. Which of the following is most likely to break a window ?

A - A 500 g ball moving at 2 m/s

B - A 300 g ball moving at 4 m/s

C - A 100 g ball moving at 9 m/s

Why did you choose this one ?

3. You and a friend, who is the same size and mass as you, are standing still facing each other on roller skates. If you push your friend what happens

(i) to you ?

(ii) to your friend ?

4. A cyclist is riding along a straight road at constant speed, when a coin falls out of his pocket. Where does the coin hit the ground relative to the cyclist ?

5. A small ball is fired into the tube shown at high speed. The tube has very smooth sides and lies on a horizontal, smooth table. The diagram shows the tube viewed from above as it lies flat on the table.

(i) Draw the path of the ball after it leaves the tube.

(ii) Describe what happens to the speed of the ball after it leaves the tube ?

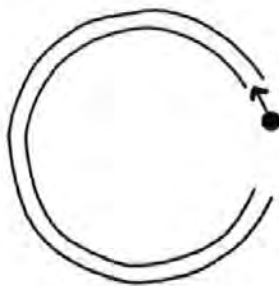


Figure 111 - Diagram for Question 5 of the Year Two Pre-Test

6. A heavy book is dropped onto a set of bathroom scales. Describe what happens to the reading on the scales.

7. A cricket ball is thrown into the air with an initial velocity shown by the arrow on the diagram.

(i) Sketch a possible path of the ball, from the point O where it is launched to the point where it bounces for the first time.

(ii) If you were to decrease the angle O without altering the magnitude of the velocity, what would happen to the horizontal distance travelled by the ball ?



Figure 112 - Diagram for Question 7 of the Year Two Pre-Test

8. On a bombing run a plane approaches its target along a straight line at constant speed. If the plane maintains this course where is it when the bombs hit the target ?

9. Two balls are exactly the same size and shape, but have masses of 1 kg and 3 kg. They are dropped at the same time from the same height.

(i) How does the time that they take to fall to the ground compare?

(ii) If this experiment were repeated on the moon, how would the results compare ?

10. The diagram is looking down on a ball on the end of a piece of string that is being swung round in a horizontal circle at fairly high speed. On the diagram draw the path of the ball if the string breaks at the point marked X.



Figure 113 - Diagram for Question 10 of the Year Two Pre-Test

11. A motorbike is overtaking a car on a motorway. How do the speeds of the two vehicles compare at the instant that they are level ?

12. A girl dives off a boat into a lake so that her motion is initially horizontal. What happens just after she loses contact with the boat

- (i) to the girl ?
- (ii) to the boat ?

13. Deep in space away from any planets an astronaut throws a small object.

- (i) Describe how it moves after it has been released ?
- (ii) When does it stop moving ?

14. The graph below shows distance against time graphs for two objects, A and B.

(i) Does B ever move faster than A ?

(ii) Do A and B ever move at the same speed ?

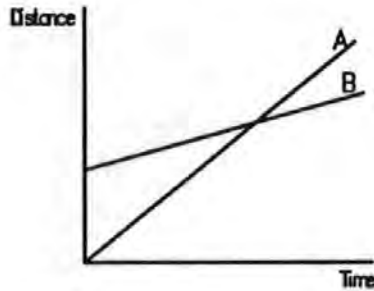


Figure 114 - Diagram for Question 14 of the Year Two Pre-Test

15. An object is resting on a smooth level surface when you start pushing it. What happens to its speed if you keep pushing it as hard as you can in a straight line ?

16. Two identical guns that are positioned side by side are aiming at the same target. Their operators calculate very different angles to fire their guns at, is it possible for them both to hit the target ? Explain why you have given this answer.

17. The graph below is a distance time graph for a jogger. Describe what is happening to the speed of the jogger :

- (i) between the points marked A and B.
- (ii) between the points marked B and C.
- (iii) between the points marked C and D.

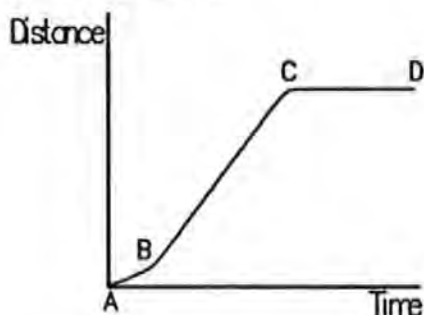


Figure 115 - Diagram for Question 17 of the Year Two Pre-Test

18. A bag of sugar is placed on a set of kitchen scales (a spring balance), which shows a reading of 1 kg. What reading would it show if it were;

- (i) dropped out of an aeroplane, while it is falling ?
- (ii) on the moon ?

19. A conker on the end of a piece of string is swung round in a vertical circle at a constant rate.

- (i) At which point on the circle is the string most likely to break ?
- (ii) If a shorter piece of string were used at the same rate of rotation, would it be more or less likely to break ?
- (iii) If a longer piece of string were used, would it be more or less likely to break?

20. A football is rolling along the dotted line shown in the diagram. When it gets to the point X it is kicked by a boot that moves in the direction shown by the solid arrow. Draw the path of the ball after it has been kicked, if the diagram shows the motion of the ball viewed from above.



Figure 116 - Diagram for Question 20 of the Year Two Pre-Test

21. A car moves along the track shown below. From A to B its speed is increasing and from B to C it is decreasing, until at C it is still momentarily before rolling back down the track. On the axes below sketch a distance against time graph for the car as it moves from A to C.

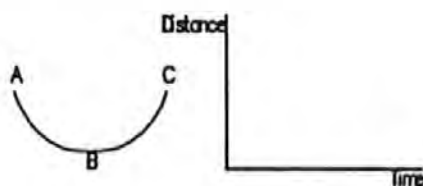


Figure 117 - Diagram for Question 21 of the Year Two Pre-Test

3 The Motion Post-Test Questions

1. What simplifying assumptions would you be making if you were to model;
 - (i) a hockey ball rolling across a playing field as a particle moving in a straight line ?
 - (ii) a planet, such as earth, moving round the sun as a particle moving in a circle?

2. A car moves along the track shown below. From A to B its speed is increasing and from B to C it is decreasing, until at C it is still momentarily before rolling back down the track. On the axes below sketch a distance against time graph for the car as it moves from A to C.

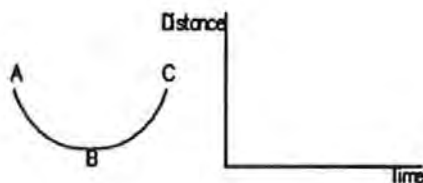


Figure 118 - Diagram for Question 2 of the Motion Questions

3. A student models the motion of a 110m hurdler as a particle moving in a straight line at constant speed. What criticisms could be made of this model ?

4. The graph below is a distance time graph for a middle distance runner completing an 800m race. Indicate on the graph the periods of time when his actual speed is greater than his average speed for the race.

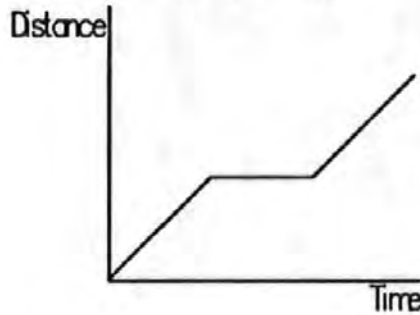


Figure 119 - Diagram for Question 4 of the Motion Questions

4 The Force Post-Test Questions Used in Year One of the Experiment

1. For each of the following situations, state whether the forces acting are in balance (equilibrium). If they are not, then state in which direction the resultant or overall force on the object is acting.

- (i) A motorbike travelling at a steady 60 mph along a straight road.
- (ii) A bouncing ball while it is in contact with the ground.
- (iii) The ball above just after it has bounced and is just clear of the ground.
- (iv) A parachutist, who is falling at a constant rate.

2. The diagram shows a rocket travelling in a straight line deep in space, where it is not effected by air resistance or gravity.

- (i) Both of its motors are turned down halving the force that they exert, what happens to the motion of the rocket ?
- (ii) If one of the motors is then turned off, what happens to the motion of the rocket ?

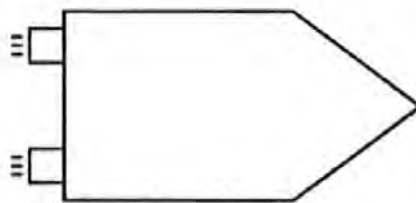


Figure 120 - Diagram for Question 2 of the Force Questions

3. Two balls are exactly the same size and shape, but have masses, of 1kg and 3kg. They are dropped at the same time from the same height.

(i) How does the time that they take to fall to the ground compare?

(ii) If this experiment were repeated on the moon, how would the results compare ?

4. The diagram shows the path of a ball as it first slides along a track and then moves through the air. Use one arrow to indicate the resultant force on the ball at each of the positions marked with a letter.

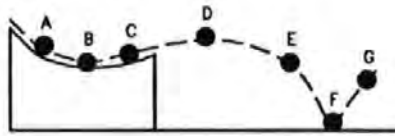


Figure 121 - Diagram for Question 4 of the Force Questions

5. The diagram below shows an air puck, X, hovering on a smooth glass table and connected by a string running over a frictionless pulley to a mass, Y. When Y is released it pulls X across the table.

- (i) What happens to the speed of the air puck X while it is being pulled by Y ?
- (ii) When the air puck, X, reaches B the string breaks, what happens to the speed of the puck after it passes point B ?

The mass Y is now replaced with another larger one that exerts twice the force on the air puck, X. The puck and the mass are released from the same initial positions as above. How does the speed of the air puck compare now with its speed when pulled by the smaller mass;

- (iii) Two seconds after they start moving ?
- (iv) When they reach B ?

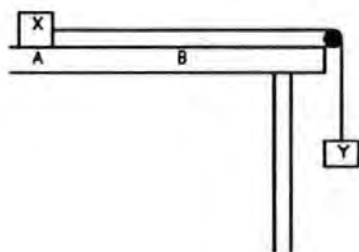


Figure 122 - Diagram for Question 5 of the Force Questions

6. An object is resting on a smooth level surface when you start pushing it. What happens to its velocity if you keep pushing it as hard as you can in a straight line?

7. In the diagram below you are looking down on a puck at rest on a smooth horizontal surface. A constant force F will act in the direction shown by the solid arrow.

(i) A second additional force is needed to drive the puck in the direction of the dotted line, draw an arrow to represent this force on the diagram.

(ii) When these two forces act simultaneously on the puck, what happens to its speed ?

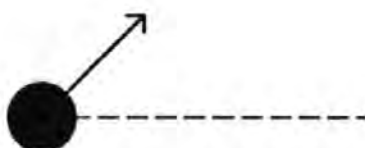


Figure 123 - Diagram for Question 7 of the Force Questions

8. A heavy atomic particle, X , exerts an attractive force, F , on a much lighter particle, Y , as shown in the diagram.

(i) Compare the force, if any, that the small particle, Y , exerts on the bigger one, X , with the force that X exerts on Y .

(ii) Which particle has the greater acceleration ? Why ?



Figure 124 - Diagram for Question 8 of the Force Questions

9. An air puck is hovering on a glass table, where it experiences no friction when it moves. What would you do to it, to make it move with a constant non-zero velocity if it is initially stationary ?

10. Two balls are exactly identical in size and shape, except that one of them is double the mass of the other. They are thrown up into the air and follow the paths shown before colliding in mid air. On the diagram indicate all the forces acting on each ball at the moment of impact. Also give all the information that you can about the nature and magnitude of these forces.

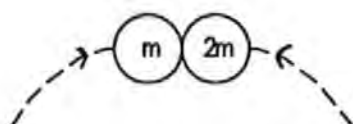


Figure 125 - Diagram for Question 10 of the Force Questions

11. During a certain stage of its flight the resultant force acting on a rocket is constant. To maintain this constant force huge quantities of fuel are used, so that the mass of the rocket decreases. After the rocket reaches a certain point it the resultant force remains the same but the loss of mass becomes negligible. During both these stages the rocket maintains a straight course. Describe the motion of the rocket.

12. A ball is thrown vertically, up in the air, as shown in the diagram. At A it is on its way up, at B it is at its highest point and at C it is on its way down.

- (i) Draw arrows to show the direction of the force at each of these three points.
- (ii) How does the magnitude of the force acting on the ball compare at each of these three points ?

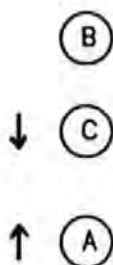


Figure 126 - Diagram for Question 12 of the Force Questions

13. A girl dives off a boat into a lake with a velocity that is initially horizontal. What happens just after she loses contact with the boat

- (i) to the girl ?
- (ii) To the boy ?

14. The diagram shows a pendulum, which swings from left to right through the points A and B. Draw arrows to show the direction of the forces (ignoring air resistance) acting on the pendulum at each of these points. Describe each of the forces that you have indicated.



Figure 127 - Diagram for Question 14 of the Force Questions

15. A bag of sugar is placed on a set of scales (a spring balance), which shows a reading of 1kg. What reading would it show if it were

(i) dropped out of an aeroplane, while it was falling ?

(ii) on the moon ?

16. A football is rolling along the dotted line shown in the diagram. When it gets to the point X it is kicked by a boot that moves in the direction shown by the solid arrow. Draw the path of the ball after it has been kicked, if the diagram shows the motion of the ball viewed from above.



Figure 128 - Diagram for Question 16 of the Force Questions

17. Deep in outer space a spacecraft is stationary. It fires its engines in such a way that they exert a force that increases uniformly in magnitude from zero to 5000 N over a five minute period.

(i) What happens to the magnitude of the acceleration of the spacecraft during this time ?

After this initial period the engines exert a constant force of magnitude 5000 N for a further five minute period. What happens to the magnitude of

(ii) the acceleration and

(iii) the velocity during this period ?

The engines are then switched off. What happens to

(iv) the magnitude of the acceleration and

(v) the velocity now ?

18. Two masses are connected by a string that passes over a pulley as in the diagram. They are of mass 5kg and 10kg and released from the positions shown. How do the forces that the string exerts on these masses compare ?

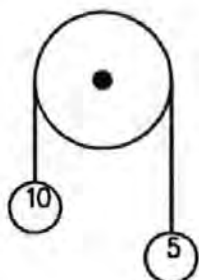


Figure 129 - Diagram for Question 18 of the Force Questions

19. You are looking down from above on a spiral tube resting on a horizontal table. A ball is shot into the tube at a high speed.

- (i) Draw the path of the ball when it leaves the tube.
- (ii) What happens to the speed of the ball as it moves across the table after it has left the tube, if the effects of friction and air resistance are negligible?
- (iii) Ignoring air resistance and friction, what forces are acting on the ball as it moves across the table ?



Figure 130 - Diagram for Question 19 of the Force Questions

20. A car is connected to a van by a tow rope. Initially both vehicles are stationary, but then the van begins to pull the car and pick up speed. While the van's speed is increasing, how does the force that the rope exerts on the car compare with the backwards force that the rope exerts on the van ?

21. A rocket drifts sideways in deep space from A to B, with its engines off and no forces acting on it. When it gets to B it fires its engines, providing a constant force until it reaches C, when the engines are turned off. On the diagram below draw a possible path for the rocket from;

- (i) B to C,
- (ii) C onwards.



Figure 131 - Diagram for Question 21 of the Force Questions

5 The Force Post-Test Questions that were Modified for Use in Year Two of the Experiment

5. The diagram below shows an air puck, X, hovering on a smooth glass table and connected by a string running over a frictionless pulley to a mass, Y. When Y is released it pulls X across the table.

What happens to the speed of the air puck X while it is being pulled by Y ?

When the air puck, X, reaches B the string breaks, what happens to the speed of the puck after it passes point B ?

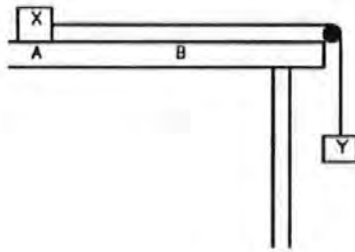


Figure 132 - Diagram for Question 5 of the Modified Force Questions

8. A heavy atomic particle, X, exerts an attractive force, F , on a much lighter particle, Y, as shown in the diagram.

Compare the force, if any, that the small particle, Y, exerts on the bigger one, X, with the force that X exerts on Y.



Figure 133 - Diagram for Question 8 of the Modified Force Questions

17. Deep in outer space a spacecraft fires its engines in such a way that they exert a constant force of magnitude 5000N for a five minute period. What happens to the velocity of the spacecraft during this time ?

After this initial period the engines exert a reduced constant force of magnitude 3000 N for a further five minute period. What happens to the velocity of the spacecraft during this period ?

The engines are then switched off. What happens to the velocity now?

6 The Momentum Post-Test Questions

1. Two identical balls are dropped from different heights at exactly the same time and allowed to fall. A is released from a height of 15 m and B from a height of 10 m. How does the momentum of the two balls compare;

(i) at the instant they are released?

(ii) one second after they are released ?

(iii) just before they land ?

(iv) On the axes below sketch graphs of momentum against time for each ball, clearly labelling both graphs.

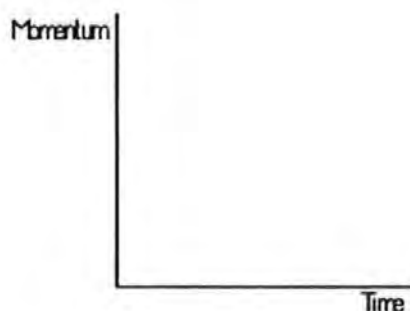


Figure 134 - Diagram for Question 1 of the Momentum Questions

2. During a certain stage of its flight the magnitude of the momentum of a rocket remains constant even though its speed is increasing. Explain why this situation could arise.

3. A student states that "momentum is a force". Do you agree or disagree with this statement ? Give reasons for your answer.

4. The diagram shows the paths of two pucks moving on a frictionless glass table. The spots indicate their positions at one second intervals. Both pucks A and B have the same mass. How does the momentum of the two pucks compare?

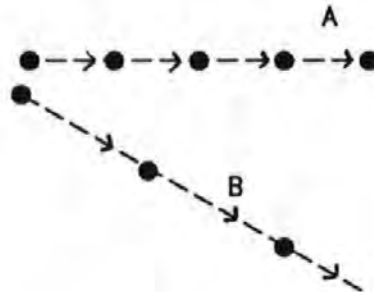


Figure 135 - Diagram for Question 4 of the Momentum Questions

5. Which would be more difficult to stop a small lorry of mass 3 tonnes travelling at 20 mph or a car of mass 1 tonne travelling at 50 mph ? Why ?

6. Which of the following is most likely to break a window ?

A - A 500g ball moving at 2m/s.

B - A 300g ball moving at 4m/s.

C - A 100g ball moving at 9m/s.

Why did you chose this one ?

6. A pool ball is moving with speed 1.8 m/s when it hits the cushion, as shown in the diagram. After this collision it is still moving at the same speed. How does the momentum of the ball before the collision compare with the momentum after the collision ?



Figure 136 - Diagram for Question 6 of the Momentum Questions

7. Two balls of mass 8 g and 16 g are fired along a straight track at different speeds. The diagram shows the position of the balls after two seconds. How does the momentum of the two balls compare ?



Figure 137 - Diagram for Question 7 of the Momentum Questions

7 The Projectiles Post-Test Questions

1. On a bombing run an aeroplane approaches its target along a straight line at constant speed. If the plane maintains this course where is it when the bombs hit the ground ?
2. A tennis ball and a cricket ball are projected with exactly the same initial velocity. If you ignore air resistance how would you expect the distance that they travel before bouncing to compare ?
3. A cricket ball is thrown into the air with an initial velocity shown by the arrow on the diagram.
 - (i) Sketch a possible path of the ball, from the point O where it is launched to the point where it bounces for the first time.
 - (ii) If you were to decrease the angle Θ without altering the magnitude of the velocity, what would happen to the horizontal distance covered by the ball ?



Figure 138 - Diagram for Question 3 of the Projectiles Questions

4. Two identical guns that are positioned side by side are aiming at the same target. Their operators calculate very different angles to fire their guns at, is it possible for them both to hit the target ? Explain why you have given this answer.

5. In a test to compare two rifles they are arranged side by side with their barrels exactly horizontal. They are then fired at the same time. It is observed that one travels further than the other before hitting the ground. How does the time of flight compare for the two bullets ?

6. The diagram shows the path of a golf ball.

(i) At each of the positions marked on its path use vectors to indicate all the forces acting on the ball (ignoring air resistance).

(ii) In order to get the ball nearer to the flag the golfer can change the angle of projection, but cannot increase the magnitude of the initial velocity. What should he do ?

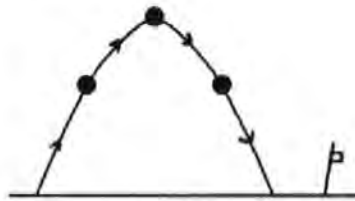


Figure 139 - Diagram for Question 6 of the Projectiles Questions

7. A car is travelling at constant speed along a straight road when a boy leans out of the window and throws a ball vertically upwards.

(i) Can the boy catch the ball ? If not where would it land ? Give reasons for your answer.

(ii) If the car were travelling at constant speed on a curved road would the boy be able to catch the ball ? If not where would it land ? Give reasons for your answer.

8. A cyclist is riding along a straight road at constant speed, when a coin falls out of his pocket. Where does the coin hit the ground relative to the cyclist ?

8 The Circular Motion Post-Test Questions

1. A car is travelling at constant speed around a bend that is exactly circular. On the diagram below use arrows to indicate the resultant force acting on the car, the air resistance and the frictional force that the ground exerts on the car. Label each arrow clearly.

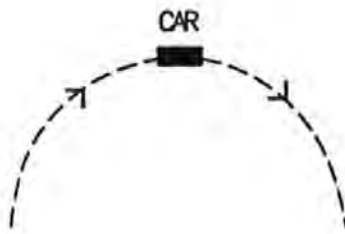


Figure 140 - Diagram for Question 1 of the Circular Motion Questions

2. Two cars on a circular roundabout are travelling at exactly the same speed, but B is much closer to the centre of the roundabout, as shown on the diagram. Give reasons to support your answers to the questions below.

- (i) Which car has the greatest rate of rotation ?
- (ii) For which car is the magnitude of the acceleration greater ?
- (iii) If the two cars had the same rate of rotation, which would have the greatest acceleration ?
- (iv) On the diagram draw an arrow to represent the resultant force on car B.

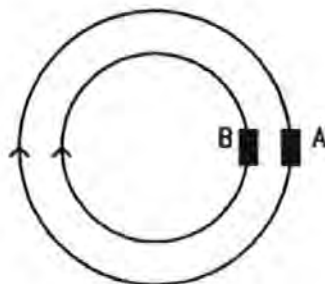


Figure 141 - Diagram for Question 2 of the Circular Motion Questions

3. The diagram shows a ball on the end of a piece of string swung round in a vertical circle at constant speed.

(i) On the diagram draw a vector and label it R , to represent the resultant force on the ball at Z .

(ii) When is the tension in the string greatest ?

(iii) When is the tension in the string least ?

(iv) If the string were longer and the rate of rotation kept the same what would happen to the tension in the string ?

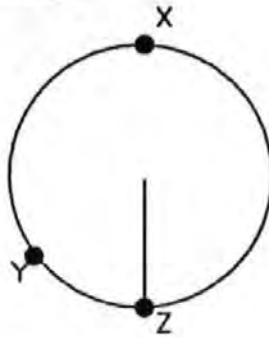


Figure 142 - Diagram for Question 3 of the Circular Motion Questions

4. As a motorcycle goes round a roundabout its speed remains constant. What happens to its acceleration ?

5. You are looking down on a roundabout in playground that is rotating quickly. A child on the roundabout, at X, is holding a ball. He aims the ball at his friend who is opposite him at Y. He then throws it at his friend.

(i) Can his friend catch it ?

(ii) Draw the path of the ball after he throws it.

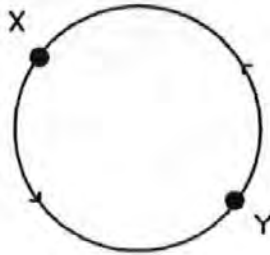


Figure 143 - Diagram for Question 5 of the Circular Motion Questions

6. The diagram is looking down on a ball on the end of a piece of string that is being swung round in a horizontal circle at fairly high speed. On the diagram draw the path of the ball if the string breaks at the point marked X.

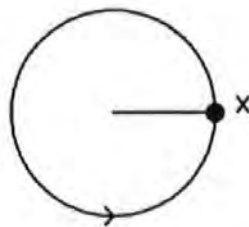


Figure 144 - Diagram for Question 6 of the Circular Motion Questions

7. The diagram below shows a loop the loop car track. When a car is released from a certain position it rises to the point B and then falls off the track. On the diagram draw arrows to represent the forces acting on the car at the points, A, while it is in contact with the track, B, at the point where it leaves the track and C, after it has left the track.



Figure 145 - Diagram for Question 7 of the Circular Motion Questions

8. Two identical coins are placed on a horizontal turn-table in the positions shown in the diagram below. The turn-table is made to rotate.

- (i) What happens to the coins as the rate of rotation is increased?
- (ii) Is there any difference between what happens to A and B ?

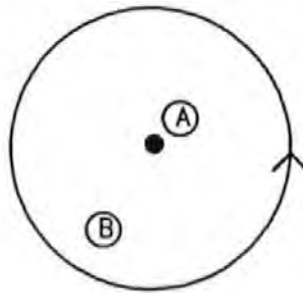


Figure 146 - Diagram for Question 8 of the Circular Motion Questions

9 The Force Hierarchy Questionnaire

1. For each of the following situations, state whether the forces acting are in balance (equilibrium). If they are not, then state in which direction the resultant or overall force on the object is acting.

- (i) A car, that was stationary, as it move away from a set of traffic lights.
- (ii) A motorbike travelling at a steady 60 mph along a straight road.
- (iii) A bouncing ball while it is in contact with the ground.
- (iv) The ball above just after it has bounced and is just clear of the ground.
- (v) A parachutist, who is falling at a constant rate.

2. The diagram shows a rocket travelling in a straight line deep in space, where it is not effected by air resistance or gravity.

- (i) Both of its motors are turned down halving the force that they exert, what happens to the motion of the rocket ?
- (ii) If one of the motors is then turned off, what happens to the motion of the rocket?

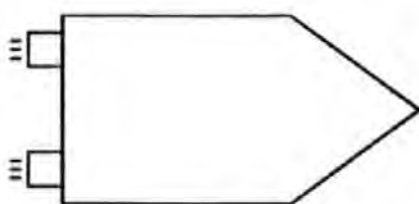


Figure 147 - Diagram for Question 2 of the Force Survey Questions

3. Two balls are exactly the same size and shape, but have masses of 1kg and 3kg. They are dropped at the same time from the same height.

(i) How does the time that they take to fall to the ground compare ?

(ii) If this experiment were repeated on the moon, how would the results compare ?

4. The diagram shows the path of a ball as it first slides along a track and then moves through the air. Use one arrow to indicate the resultant force on the ball at each of the positions marked with a letter.

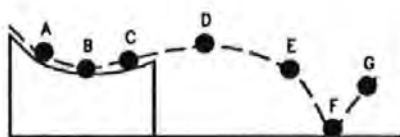


Figure 148 - Diagram for Question 4 of the Force Survey Questions

5. The diagram below shows an air puck, X, hovering on a smooth glass table and connected by a string running over a frictionless pulley to a mass, Y. When Y is released it pulls X across the table.

(i) What happens to the speed of the air puck X while it is being pulled by Y ?

(ii) When the air puck, X, reaches B the string breaks, what happens to the speed of the puck after it passes point B ?

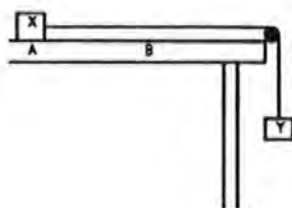


Figure 149 - Diagram for Question 5 of the Force Survey Questions

6. A spaceship is stationary in deep space. It fires its engines so that they exert a constant force for a two minute period and are then turned off.

(i) On the axes below sketch a graph of speed against time for the motion of the spaceship.

(ii) Also sketch a graph, of speed against time for an identical spaceship that is carrying a heavy load, on the same set of axes.

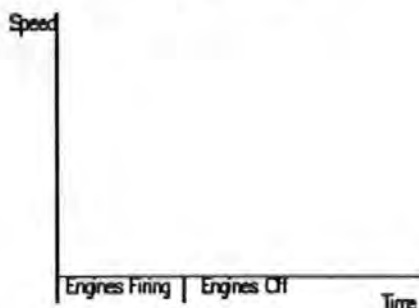


Figure 150 - Diagram for Question 6 of the Force Survey Questions

7. An object is resting on a smooth level surface when a force is applied to it. What happens to its velocity if the force is not removed ?

8. In the diagram below you are looking down on a puck at rest on a smooth horizontal surface. A constant force F will act in the direction shown by the solid arrow.

(i) A second additional force is needed to drive the puck in the direction of the dotted line, draw an arrow to represent this force on the diagram.

(ii) When these two forces act simultaneously on the puck, what happens to its speed ?

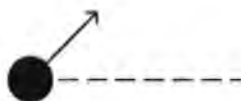


Figure 151 - Diagram for Question 8 of the Force Survey Questions

9. A heavy atomic particle, X, exerts an attractive force, F , on a much lighter particle, Y, as shown in the diagram.

Compare the force, if any, that the small particle, Y, exerts on the bigger one, X, with the force that X exerts on Y.



Figure 152 - Diagram for Question 9 of the Force Survey Questions

10. An air puck is hovering on a glass table, where it experiences no friction when it moves. What would you do to it, to make it move with a constant non-zero velocity if it is initially stationary?

11. Two balls are exactly identical in size and shape, except that one of them is double the mass of the other. They are thrown up into the air and follow the paths shown before colliding in mid air. On the diagram indicate all the forces acting on each ball at the moment of impact. Also give all the information that you can about the nature and magnitude of these forces.

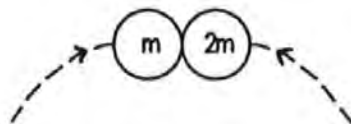


Figure 153 - Diagram for Question 11 of the Force Survey Questions

12. During a certain stage of its flight the resultant force acting on a rocket is constant. To maintain this constant force huge quantities of fuel are used, so that the mass of the rocket decreases. After the rocket reaches a certain point it the resultant force remains the same but the loss of mass becomes negligible. During both these stages the rocket maintains a straight course. Describe the motion of the rocket.

13. A ball is thrown vertically, up in the air, as shown in the diagram. At A it is on its way up, at B it is at its highest point and at C it is on its way down. Draw arrows to show the direction of the force at each of these three points.

How does the magnitude of the force acting on the ball compare at each of these three points ?

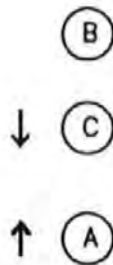


Figure 154 - Diagram for Question 13 of the Force Survey Questions

14. The two diagrams below show a book resting on a table and a ball hanging on a length of string. On each diagram mark in the forces that are acting on the book and the ball.

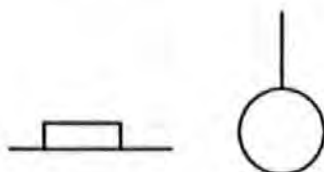


Figure 155 - Diagram for Question 14 of the Force Survey Questions

15. The diagram shows a pendulum, which swings from left to right through the points A and B. Draw arrows to show the direction of the forces (ignoring air resistance) acting on the pendulum at each of these points.

Describe each of the forces that you have indicated.

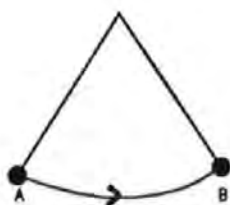


Figure 156 - Diagram for Question 15 of the Force Survey Questions

16. A bag of sugar is placed on a set of kitchen scales (a spring balance), which shows a reading of 1kg. What reading would it show if it were

- (i) dropped out of an aeroplane, while it was falling ?
- (ii) on the moon ?

17. A football is rolling along the dotted line shown in the diagram. When it gets to the point X it is kicked by the point of a boot that moves in the direction shown by the solid arrow. Draw the path of the ball after it has been kicked, if the diagram shows the motion of the ball viewed from above.

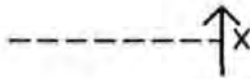


Figure 157 - Diagram for Question 17 of the Force Survey Questions

18. Deep in outer space a spacecraft is stationary. It fires its engines in such a way that they exert a force that increases uniformly in magnitude from zero to 5000 N over a five minute period.

(i) What happens to the magnitude of the acceleration of the spacecraft during this time ?

After this initial period the engines exert a constant force of magnitude 5000 N for a further five minute period. What happens to

(ii) the magnitude of the acceleration and

(iii) the velocity during this period ?

The engines are then switched off. What happens to the magnitude of

(iv) the acceleration and

(v) the velocity now ?

19. Two masses are connected by a string that passes over a pulley as in the diagram. They are of mass 5kg and 10kg and released from the positions shown. How do the forces that the string exerts on these masses compare ?

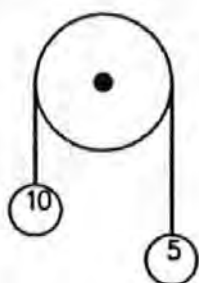


Figure 158 - Diagram for Question 19 of the Force Survey Questions

20. You are looking down from above on a spiral tube resting on a horizontal table. A ball is shot into the tube at a high speed.

- (i) Draw the path of the ball when it leaves the tube.
- (ii) What happens to the speed of the ball as it moves across the table after it has left the tube, if the effects of friction and air resistance are negligible?
- (iii) Ignoring air resistance and friction, what forces are acting on the ball as it moves across the table ?



Figure 159 - Diagram for Question 20 of the Force Survey Questions

21. Two children of equal mass climb onto a see saw that is held in the position shown. If it is initially at rest and the children sit at the points marked A and B, what happens when it is released ?



Figure 160 - Diagram for Question 21 of the Force Survey Questions

22. A rocket drifts sideways in deep space from A to B, with its engines off and no forces acting on it. When it gets to B it fires its engines, providing a constant force until it reaches C, when the engines are turned off. On the diagram below draw a possible path for the rocket

(i) from B to C,

(ii) and then from C onwards.

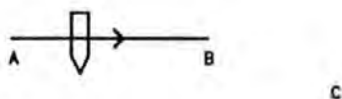


Figure 161 - Diagram for Question 22 of the Force Survey Questions

10 The Momentum Hierarchy Questionnaire

1. Two identical balls are dropped from different heights at exactly the same time and allowed to fall. A is released from a height of 15 m and B from a height of 10 m. How does the momentum of the two balls compare;

- (i) at the instant they are released?
- (ii) one second after they are released ?
- (iii) just before they land ?

2. A puck moving with constant velocity strikes an identical stationary puck of the same mass and stops dead. How does the velocity of the second puck after the collision compare with the velocity of the original puck before the collision ?

3. During a certain stage of its flight the magnitude of the momentum of a rocket remains constant even though its speed is increasing. Explain why this situation could arise.

4. Explain very briefly the safety advantage of having cars that are designed to crumple in accident rather than cars that are very rigid.

5. An astronaut floating deep in space catches a ball that has been thrown to him. Describe as fully as possible what would you expect to happen to him ?

6. The diagram shows the paths of two pucks moving on a frictionless glass table. The spots indicate their positions at one second intervals. Both pucks A and B have the same mass. How does the momentum of the two pucks compare?

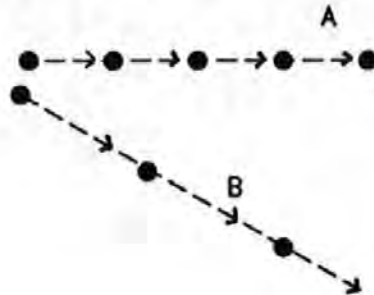


Figure 162 - Diagram for Question 6 of the Momentum Survey Questions

7. Which would be more difficult to stop a small lorry of mass 3 tonnes travelling at 20 mph or a car of mass 1 tonne travelling at 50 mph? Why?

8. A puck of mass 1kg is moving with speed 1.8 m/s when it hits a barrier, as shown in the diagram. It rebounds still moving at the same speed.

(i) How does the momentum of the puck before the collision compare with the momentum after the collision?

(ii) On the diagram, using the same scale, draw a vector to represent the impulse that acts on the puck.

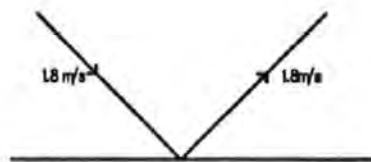


Figure 163 - Diagram for Question 8 of the Momentum Survey Questions

9. Two balls of mass 8g and 16g are fired along a straight track at different speeds. The diagram shows the position of the balls after two seconds. How does the momentum of the two balls compare ?



Figure 164 - Diagram for Question 9 of the Momentum Survey Questions

10. Two pucks, that are initially at rest, have different masses, one being much greater than the other. If they are subjected to the same constant force for five seconds, how will the momentum of the two pucks compare when the force is removed ?

11. When fairly hard objects like snooker balls collide, momentum is conserved. Is momentum conserved when softer spongy objects collide ?

12. When a small train moving on a track collides with a heavier stationary one the small one begins to move backwards and the heavy one begins to move forwards. How does the momentum of the heavy train after the collision compare with the initial momentum of the light one ?

13. The diagram shows the path of a puck viewed from above. Initially it slides along the dotted line shown at constant speed, when it gets to X a force, in the direction indicated by the arrow, is exerted on it for a very short time.

(i) Draw the path of the ball after this ?

(ii) How does the magnitude of the momentum of the puck now compare with what it was before ?

(iii) If a puck of twice the mass moving at the same speed is subjected to the same force for the same time, also draw its path on the diagram.

(iv) If the original puck is then used again but initially moving with twice the original speed, draw its path on the diagram.

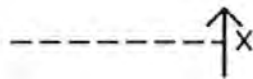


Figure 165 - Diagram for Question 12 of the Momentum Survey Questions

14. Which of the following is most likely to break a window ?

A - A 500g ball moving at 2m/s.

B - A 300g ball moving at 4m/s.

C - A 100g ball moving at 9m/s.

Why did you chose this one ?

15. A moving puck, A, of mass 1kg collides with a stationary puck, B, of the same mass. The diagram below shows the velocity vectors of the two pucks after the collision. Draw and label a vector to represent the initial momentum of the puck that was moving before the collision, showing how you obtain them. Also draw and label a vector to represent the impulse that is exerted on moving puck during the collision.

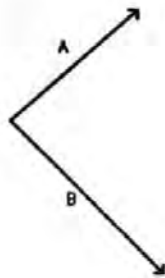


Figure 166 - Diagram for Question 15 of the Momentum Survey Questions

16. A skater follows a curved path, moving at constant speed. What happens to the skaters momentum ?

17. A stationary ball, A, is hit by a moving ball, B, which loses its motion during the collision. If ball A, that was stationary moves faster after the collision than ball B did before, how do the masses of the two balls compare ?

18. A small ball bearing is fired along the centre line of the rectangular table shown in the diagram. In the centre it collides with another ball bearing of the same size and mass and changes direction as shown. (i) Sketch a possible path for the other ball.

(ii) Is it possible to say which one will hit the side of the table first ?

(iii) If so which one ?

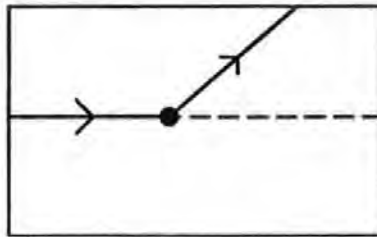


Figure 167 - Diagram for Question 18 of the Momentum Survey Questions

19. Two people on roller skates are standing facing each other. One pushes hard against the other and they move apart. If one person is much heavier than the other how does;

(i) the momentum of each skater compare ?

(ii) The speed of each skater compare ?

20. Two pucks, A and B, have masses of 1kg and 2kg respectively. Initially mass A is moving towards B which is stationary. The vectors in the diagram show the velocities of A and B after the collision. Draw a vector to represent the initial velocity of A, showing how you obtain it.

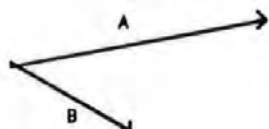


Figure 168 - Diagram for Question 20 of the Momentum Survey Questions

11 The Background Information Questionnaire

Name _____

Age _____

Sex _____

Mathematics teacher _____

Please list any other A-level courses
that you are taking.

Please list any other courses that you are taking.

Please list all the GCSE / CSE / GCE
subjects that you have studied and the grades that you obtained.

12 The Student Video Evaluation Questionnaire

Name _____

Title of video _____

Please circle the answer to each of the questions below.

1. How would you rate the sound quality ?

Excellent Good Poor Very Poor

2. How would you rate the picture quality ?

Excellent Good Poor Very Poor

3. How interesting did you find the video ?

Very interesting Interesting Boring Very boring

4. How would you rate the quality of the explanation on the video ?

Excellent Good Poor Very Poor

5. How well do you feel that you understood the video ?

Very well Well Not very well Not at all

Please answer each question briefly.

6. What did you like most about the video ?

7. What did you dislike most about the video ?

8. Was there anything about the video that you would like to change ?

9. What do you think that you learned from the video ?

13 The Staff Video Evaluation Questionnaire

Title of video _____

The picture quality was:

Good Fair Poor

The sound quality was:

Good Fair Poor

Student interest in the video was:

High Fair Low

The video achieved its teaching aims:

Yes In Part No

The number of teaching points was:

Too Many Just Right Too Few

The level of the video was:

Too High Just Right Too Low

The pace of the video was:

Too Fast Just Right Too Slow

The presentation of the video was:

Good Fair Poor

Would you use this video again:

Yes Unsure No

Please add any comments you have about the video.

Appendix D - The Product-Moment Correlation Coefficient for Dichotomous Data

The product-moment correlation coefficient for dichotomous data, often referred to as phi, is used extensively by psychologists to determine whether there exists any association between the attributes of or responses given by the members of a sample under investigation. It is a measure that has been used extensively in this type of research and facilities for its computation are readily available.

If two test questions are to be compared the procedure for calculating phi is as follows;

(i) The responses of the students to the two test items are first cross-tabulated to give a table as below;

Number of Students in each Category	Question 1	
	Incorrect Response	Correct Response
Question 2 Correct Response	a	b
Incorrect Response	c	d

Table 135 - Crosstabulation of Results for the Phi Coefficient

(ii) The coefficient is then calculated using the formula below;

$$\text{phi} = \frac{bc - ad}{((a+b)(a+c)(b+d)(c+d))^{1/2}}$$

If there is a high association between the questions used in the research then students will tend to either get both questions correct or both incorrect. In a case of perfect association both a and d would both be 0, leading to a phi value of 1. If there is no association between the two questions then the students would be randomly distributed to the four categories. Considering the extreme example where a, b, c and d are equal, then the phi value is 0. Between these two extremes phi takes a value of between 0 and 1, the greater this value the greater the association. If there is an inverse association the phi would take a negative value. In no cases in the research was a negative value of phi obtained.

Appendix E - Publications of the Author related to the Reported Studies

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