AN INVESTIGATION OF THE UNDERSTANDING OF CONCEPTS IN MECHANICS BY PUPILS IN SCOTTISH SECONDARY SCHOOLS

by

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SUMMARY

The present investigation of pupils' understanding of concepts in mechanics originated from a preliminary study carried out in 1974-76 by Johnstone and Mughol at Glasgow University. Details of this preliminary study are given in chapter 1.

Chapter 2 is a survey of the relevant literature on concept learning. A useful model of concept development is that proposed by Klausmeier, in which there are four sequential stages. The 'formal' level of concept development requires that the learner can not only name the concept and discriminate between examples and non-examples, but also state, in terms of the critical attributes of the concept, the rule by which such discriminations are made. In our investigation, we have used this as a guide to assess the pupils' conceptual understanding.

Also in chapter 2, we give an account of the learning theories of Bruner, Piaget, Ausubel and Gagne, and suggest that Ausubel's learning theory is most relevant to our investigation. We also describe some practical techniques for mapping 'cognitive structure', and discuss the relationship of short-term memory to working memory to long-term memory in the processing of information, in which 'information overload' may be a very important factor.

In chapters 3 and 4 we describe two separate preliminary studies which were undertaken to clarify some points arising from the Johnstone and Mughol study and to collect empirical data on the pupils' understanding of the concepts of '<u>momentum</u>' and '<u>energy</u>'. The results of the teacher questionnaire, described in chapter 3, indicate that teachers tend to assume that some pupils are unlikely ever to acquire a 'formal'

understanding of such concepts. The results of the multiple-choice pupil tests, described in chapter 4, indicate that pupils can recall the defining equations for such concepts and can solve simple problems involving such concepts. However their ability to manipulate several concepts at the same time or to apply several concepts in succession is very limited. There is a significant improvement in performance as the pupil gains more experience of using the concepts. This, we suggest, is not wholly due to maturation. It is more likely due to an increased elaboration of the pupil's cognitive structure.

In chapter 5 we describe how we came to devise a new technique for assessing concept attainment. Having decided to include the concepts of 'force' and 'impulse' in our investigation, and to concentrate on the 'formal', scientific understanding of the concepts, we developed two complementary techniques for exploring the pupils' cognitive structure. The first technique looks at the pupil's ability to select, from his own body of knowledge, patterns and relationships, to discard irrelevant material and to 'home in' on the concept under consideration. This is done by describing a concept X by giving a series of nine clues, each one more informative, and asking the pupil to select concepts to fit the clues until he can narrow down to a single concept only and identify the concept X. The clues range from the very general (e.g. "The quantity X is proportional to the mass of a body") to the very specific (e.g. "The quantity X is defined by the equation $W = mg$") The number of valid concept names included in the pupil's response at each stage gives a measure of the'breadth' of the pupil's understanding of such concepts.

At each stage, the pupil is asked to state, on a 1-5 scale, the degree of confidence with which he makes his choice. Level 1 corresponded to 'just guessing' and Level 5 to 'I know I'm right'. This confidence level should increase as the number of clues increases. Where the confidence level shows a sudden drop, we may infer that either the clue cannot be meaningfully assimilated into the pupil's cognitive structure or the clue tells the pupil his suggested concept is wrong,

The other technique is to offer, in a 5 x 5 grid format, a large number of pieces of information, each of which may be taken to be an instance of a particular concept, and to ask the pupil to select all the pieces relevant to a particular concept. In each of the numbered boxes on the grid, there is a quantity 'X' and the pupils are instructed to identify this quantity X which, they are told, could be '<u>momentum</u>', '<u>kinetic energy</u>', '<u>gravitational potential energy</u>', '<u>force</u>' or '<u>impulse</u>'.

In chapter 6, we describe how this material was field tested, in 1979-80, on 380 subjects, including O-Grade pupils, H-Grade pupils, B.Sc.students, HND students, student teachers and experienced physics teachers. The results of this field test reveal that the teachers and B.Sc. students can give significantly more 'valid' concepts than any other group. In terms of the number of 'valid' concepts identified on the 5 x 5 grid, the B.Sc. student is on a par with the teacher of physics, the H-Grade pupil is on a par with the HND student and the O-Grade pupil is on a par with the student teacher of Chemistry/Biology. The number and variety of the 'valid' responses increases as we go from O-Grade pupil to H-Grade pupil to B.Sc. student. This we interpret as an increased concept understanding. There is evidence that the level of concept understanding decreases if the concept is not being frequently used.

The results show that there is no significant difference in performance in identifying the defining equation or the units for each concept, but the O-Grade pupil is much poorer at generalising all possible instances of the concept. There is also some evidence that pupils have difficulty in interpreting diagrams and graphical representation of information.

The grid of numbered boxes has been revised in the light of the results of the 1979-80 field trial and the revised version was validated by some 30 experienced teachers of physics. In the 1980-81 field trial, the consensus opinion of this group as to what were 'relevant' boxes for each concept was used as an 'ideal choice' against which the pupils' choices were compared. This is described in chapter 7, which also includes an analysis of the 1980-81 field trial, in which the revised test material was trialled in 20 secondary schools throughout Scotland on 429 H-Grade pupils .

The test material, as used in the 1980-81 field trial, is in three parts, A, B and C. Part A is the revised 5 x 5 grid of numbered boxes. Part B is a somewhat shortened version of the 'What is the quantity X' test used in the previous material. This time the pupil's '<u>confidence rating</u>' is used to determine the number of clues he was given. The pupil is allowed to ask one question of his own choosing at the penultimate stage. The pupil is required to state the defining equation for his chosen concept and to give two more important facts about the concept.

In Part C, another technique is introduced. A 3 x 4 grid of numbered boxes is provided. Each box contains a '<u>proposition</u>' (a relationship between concepts). Four conventional extended-answer questions taken from recent S.C.E. H-Grade physics papers are provided, and the pupil is asked to select from the grid the appropriate sequence of propositions he would use to solve these problems. The pupil is not required to work out a numerical answer to any of the given problems, only to select and sequence the propositions to be used.

The results of the 1980-81 trials confirm much of what was found in the 1979-80 trials, but the revised format makes it easier to diagnose individual pupil misunderstandings. We suggest, in chapter 8, that the techniques used in the 1980-81 trials may also be used to some advantage by the classroom teacher in diagnosing pupils' difficulties in concept understanding and in generally improving the pupils' concept learning.

Our investigation of pupils' understanding of mechanics concepts has identified more clearly the nature of the difficulties the pupils are likely to have, and has suggested some ways in which the teacher may be able to help the pupils by diagnosing their lack of understanding and by improving their overall competence in handling abstract concepts.

CHAPTER 1 - BACKGROUND INFORMATION

Introduction

In this chapter we will describe the origins of the present research and give some necessary background information about the organisation of secondary education in Scotland and, in particular, about the Scottish Certificate of Education physics syllabuses.

Origins of present research

The present investigation into pupils' understanding of basic concepts in mechanics has its origin in a preliminary study of the relative difficulty of a number of physics concepts included in the Scottish Certificate of Education Ordinary and Higher Grade syllabuses. In this study, carried out by Johnstone and Mughol (1) during 1974-76, some 1200 secondary school pupils and some 200 first-year university students were asked to categorise concepts, from a list of 23 basic physics concepts, under one of four headings:

(1) Never studied.

(2) Easy to understand i.e. I got the idea first time.

(3) Difficult to understand i.e. I now understand this but I had difficulty in doing so.

(4) Never understood i.e. even after several attempts I still do not understand it.

The results from this subjective assessment are shown graphically in Figure 1 (overleaf) which is reproduced from the original article in Physics Education.

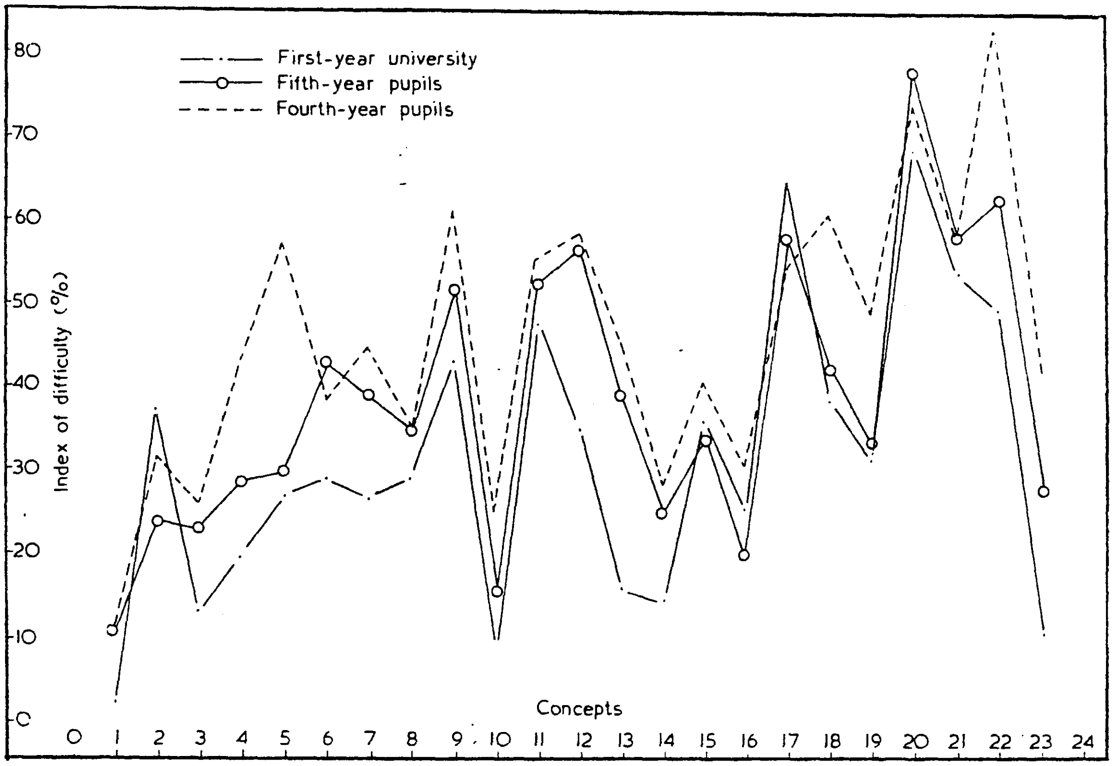


Figure 1 Plot of index of difficulty against topic number for the subjective assessment

The three graphs show a marked similarity which suggests that the subjective assessment of 'difficult' topics is consistent between the groups, and the 'difficult' topics for the university group (who had passed through the school system) are also proving difficult to the pupils still at school.

These subjective reports of 'difficult' concepts were largely confirmed by the results of a specially constructed objective test battery, which had at least three items for each of the basic concepts on the original list. In other words, the concepts which pupils perceived as difficult were also the ones for which the mean score in the objective test was low.

The results showed that many pupils reported difficulty in understanding basic concepts in two main areas of the syllabus. These were mechanics (e.g. idea of uniform motion, conservation of momentum, elastic and inelastic collisions, energy and power) and electricity (e.g. current, resistance, e.m.f., electric and magnetic fields, electromagnetic induction).

The fact that the 'difficult' concepts can be grouped under only two headings may suggest some gross imbalance in the original list of concepts. This is not the case. The original list of 23 concepts had much the same relative weighting of topics as the S.C.E. Physics syllabuses (2), in which Newtonian mechanics and Electricity together account for about 60-70% of the syllabus content.

The list of 23 basic concepts used in the Johnstone and Mughol study was, of necessity, a selection of all the possible concepts which one might expect to encounter in a school physics syllabus. It is more than likely that, if a longer list of concepts had been provided, the pupils would have identified still more concepts which were 'proving troublesome'. For example, the concept of '<u>acceleration</u>' would almost certainly have been categorised as 'difficult' by most pupils.

Rae et al (3) have investigated the difficulties experienced by S.C.E. O-Grade pupils in dealing with problems involving acceleration, and have highlighted both <u>conceptual</u> difficulties (e.g. many pupils have serious problems in distinguishing velocity from acceleration) and <u>computational</u> difficulties (e.g. vulgar fractions present many pupils with insurmountable problems). Among other things, they recommended that

(1) Strenuous efforts should be made to develop new methods of measuring acceleration. Such methods would not include ticker timers and should ideally produce values of velocity at known time intervals.

(2) Learning hierarchies combined with diagnostic testing should be more widely used in the teaching of physics.

(3) The structure, content and teaching order of the whole of Section J (Newtonian mechanics) of the Ordinary grade syllabus should be reviewed.

It should not be imagined that the difficulties pupils were having with concepts in mechanics had gone unnoticed by the Scottish Certificate of Education Examination Board (4). In the 1972 Examiners' Report we read

> "Some concern must be expressed about the lack of understanding of some of the fundamental physics of the 'O' and 'H' grade courses among the weaker candidates",

while in the 1974 Report we find

> "At Higher grade, where questions demand precise knowledge, it becomes clear that many see no distinction between energy and momentum, and have little knowledge or appreciation of the latter".

In the 1980 Report, the following comment was made regarding the general performance of H-Grade candidates in a problem involving momentum.

> "This was not well done. Explanations were generally poor and it was apparent that the physics of the situation was not understood by many."

The Johnstone and Mughol study described earlier was undertaken "to establish which of the concepts taught in school physics are proving troublesome, so that a systematic investigation of each of them may be undertaken to establish the cause of the difficulty". This has been the function of the present investigation in the area of mechanics. However, before describing the present investigation in any detail, it may be helpful to outline the general background to the investigation.

Science education in Scotland has certain identifiable features which distinguish it from the pattern in other areas of Britain.

(1) Science is only taught in secondary schools i.e. from the age of 12+.

(2) For the first two years of secondary education (S1,S2) all pupils follow a common integrated science course. Thereafter the separate sciences (physics, chemistry, biology) are taught to Ordinary Grade (S4) and Higher Grade (S5) to pupils who choose science. Most of these pupils will study two science subjects.

(3) All science teachers are graduates and must have successfully completed a course of teacher training before being appointed to a school.

(4) The syllabuses in science are determined centrally for all schools in Scotland by the Scottish Central Committee on Science.

(5) The Ordinary and Higher Grade examinations are also centrally controlled by the Scottish Certificate of Education Examination Board.

In Scotland, science teaching at secondary school level is a three-staged process, the first part of which is observational in nature, the second is more interpretive with some quantification of concepts, while the third is the generalisation and further refinement of concepts (5). These three stages, or <u>cycles</u>, enable basic concepts to be introduced through simple, concrete experiences at an early stage and then to be gradually refined and made more quantitative and abstract in the later stages.

This curriculum model owes much to the three stages of intellectual development or 'levels of knowing' (enactive through iconic to symbolic) proposed by Bruner (6). Thus, in years 1 and 2, certain basic concepts (e.g. energy and force) are introduced through practical experience. In years 3 and 4 these concepts are examined again in more detail and the ideas are quantified. In year 5, the concepts are still further developed and extended, using mathematics, to a highly abstract level. This is illustrated in the following extracts from the S.C.E. Physics syllabuses (2).

(First cycle) - Integrated Science Course.

S1	(Age 12-13)	Basic idea of energy - brief introduction to various forms of energy including kinetic (motion) and potential (stored) energies - qualitative ideas of energy interconversions.
S2	(Age 13-14)	Idea of force as lifting, pulling, pushing, stretching, compressing or turning - effect on shape and on motion - motion without force as a fundamental idea - gravity - introduction of newton as unit of force - action/reaction pairs of forces - work as measure of energy transferred - joule = newton metre.

(Second cycle) - Ordinary Grade.

S3/S4	(Age 14-16)	Kinematics by graphical methods - vectors - physical ideas of Newton I and Newton II - $F = ma$ - definition of newton - vector addition of forces - resolution of forces - conservation of linear momentum - Newton III - work as measure of energy transformed -

power as rate of doing work - quantitative treatment of potential and kinetic energies - $E_p = mgh$ - $E_k = \frac{1}{2} mv^2$ derived from $F = ma$.

(Third cycle) - Higher Grade

S5 (Age 16-17) Kinematics using equations of motion - Newton II in terms of rate of change of momentum - Newton III related to conservation of momentum - impulse - energy in elastic/inelastic collisions - collisions in two dimensions.

Leboutet-Barrell (7) has suggested that, in the area of mechanics, there are "between fifteen and twenty basic concepts". In our study, we have tried to restrict the number of concepts involved. Initially, working from the results of the 1976 study of Johnstone and Mughol, we concentrated on only two concepts ('momentum' and 'energy') but latterly we felt obliged to include also the concepts of 'force' and 'impulse', which are directly related to changes of momentum and/or energy.

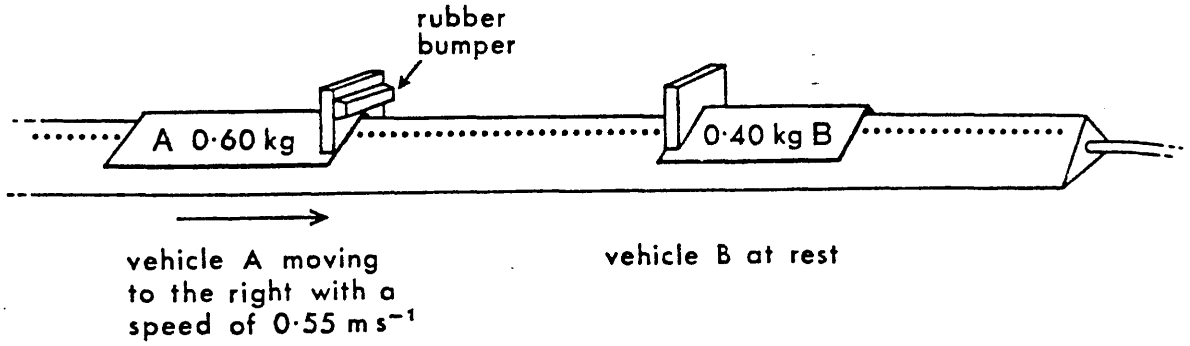
The study of mechanics, even at a fairly elementary level, will soon involve the learner in the complex web of inter-related concepts which makes up the logical, theoretical structure of the material. The pupil's understanding of mechanics concepts must necessarily involve not only a knowledge of the basic concepts (e.g. momentum, energy, force) but also, and perhaps more importantly, the inter-relationships between these concepts. As we shall describe in more detail later, we found it difficult to separate these two factors.

Throughout the research, we have concentrated on the pupils' understanding of certain specific concepts which they encounter during their formal study of physics. This has meant we have only involved pupils who had already met these concepts. At various stages in the research, we have used different groups of pupils to try out materials. These field trials will be described in detail later but, at this stage, we should perhaps mention that, because of the nature and level of the material being tested, we were restricted to using as subjects pupils who were at least at O-grade level in physics. In other words, the composition of the test population must be kept in mind when considering the results from the field trials and, by the same token, it is unlikely that these results will provide much information about the growth of the concepts prior to the stage of O-grade.

Finally, to highlight the relevance of the present investigation, we would draw attention to the following question which appeared in the S.C.E. H-Grade Physics Paper II in 1978.

Marks

2. A linear air track was used to study collisions between two vehicles, A and B. Vehicle A had a block of hard rubber mounted on it, to act as a bumper. Vehicle B had no rubber bumper.



Vehicle A had a mass of 0·60 kg and was projected with a speed of 0·55 m s^{-1} towards vehicle B. Vehicle B had a mass of 0·40 kg and was initially at rest. After being struck by vehicle A, vehicle B moved off with a speed of 0·27 m s^{-1}.

(*a*) Describe how you would measure the time of contact during the collision. 2

(*b*) (i) Calculate the impulse on vehicle A during the collision.

(ii) Explain how you could now use the time of contact to find the average force on vehicle A during the collision. 3½

(*c*) The experiment was repeated with a block of soft rubber on vehicle A instead of the hard rubber. The masses of the vehicles and the initial speed of vehicle A were the same as in the first experiment and vehicle B was again initially at rest. The final speeds of vehicles A and B were found to be exactly the same as before.

During the second collision how do (i) the impulse, (ii) the average force, (iii) the time of contact, compare with those of the first experiment? Explain your reasoning in each case. 4½

(10)

At first glance, it appears a reasonable enough question, until one looks more closely at the actual numerical values given in the question. It was noted that, of a random sample of over 220 scripts marked, 42 candidates worked out (correctly) that vehicle A after the collision was still moving at 0.37 ms^{-1} in its original direction. This result did not conflict in their minds with the given statement that 'vehicle B moved off with a speed of 0.27 ms^{-1}' Only 3 candidates from the whole sample indicated that they were even aware of the unrealistic values given in the question, which imply that, after the collision, A and B are moving in the same direction and that A is moving faster than B !!

CHAPTER 2 - A REVIEW OF THE RELEVANT LITERATURE.

Introduction

In this chapter, we will report our findings from a review of the literature in several different areas, all of which seemed relevant to our investigation. We have grouped our findings under five main headings.

(a) Concepts and concept learning
(b) Learning theories
(c) Mapping cognitive structure
(d) Information overload
(e) Some further relevant references.

We have included, where appropriate, quotations from the original sources. We feel that such quotations can often convey the message much better than any paraphrase or summary we might provide. At the same time, we have tried to avoid having too many such quotations, since detailed references to the original sources are given in an appendix (See page 279)

(a) Concepts and concept learning

Having embarked on an investigation of concepts in mechanics, it seemed only reasonable that we should start by considering what is meant by a concept and how concepts are learned.

Although there are numerous references in the educational literature to concepts and conceptual learning, there are not too many definitions of the term 'concept'. Novak (8) has noted that "concepts are much discussed in education, but seldom defined." It may be that this is intentional. If most concepts are formed by abstracting common features from a series of experiences and not by definition, then we should be able to understand the meaning of the term 'concept' by considering various situations in which the term is used. In other words, we should be left to form our own concept of a concept. This is illustrated in the following extract (9).

"What is a Concept? To a psychologist, conceptual behaviour involves generalising within classes and discriminating between classes. An individual discriminates between things when he makes different responses to different things. He generalises among things when he makes the same response to different things. When he makes the response 'triangle' to any three-sided figure and the response 'quadrilateral' to any four-sided figure, he is discriminating between triangles and quadrilaterals and he is generalising among triangles and among quadrilaterals. In general, when he makes the same response to some members of a set and different responses to other members of the set, then he is both discriminating and generalising among members of the set, and a psychologist would say he has a 'concept'."

Klausmeier et al (10) define a concept as "ordered information about the properties of one or more things - objects, events, or processes - that enables any particular thing or class of things to be differentiated from and also related to other things or classes of things".

Markle and Tiemann (11) consider a concept to be "a class or category all the members of which share a particular combination of critical properties not shared by any other class". White (12) puts it more simply: "Concepts are classifications". Novak (8) has found the ideas of Gowin helpful in clarifying his concept of concept. "Gowin sees concepts as regularities in facts designated by some culturally agreed upon sign or symbol (e.g. the word 'concept'). Facts in turn are records of events, and events are anything that happens or can be made to happen. Therefore, concepts are inventions of man used to describe observed regularities in events".

In Peel's (13) view, a concept has three parts: "first there is the extensive array of instances grouped together and those excluded; secondly there is the rule or law or common property by which the elements in the array are put together; finally there is the arbitrary name given to the concept."

Schaefer (14) describes a concept as having "a logic core which is surrounded by an associative framework, to which also the name of the concept belongs. The logic core is a pattern of properties of a class of things, which is invariant to individual objects of the class as well as to the observer".

The most helpful description of a concept we came across was that given by Hurd (15):

"A concept is a synthesis or logical relationship given to relevant information by the individual; it is a product of his own imagination, insight or reasoned judgement. A concept is more than a collection of organised facts .... Concepts have a logical order making the facts within the concepts meaningful and therefore useful in thinking."

This description emphasises that concepts are mental constructs which help us to organise information in a meaningful way. Unlike facts, which are unalterable, concepts are dynamic structures, capable of modification to accommodate and integrate new information in a meaningful way.

> "As more information is assimilated, the original concept is reorganised, its meaning extended, as well as its discriminatory and predictive powers. The economy of learning concepts results from more coming out than going into the learning; understanding is increased and thought is amplified" (15).

We get, from Hurd's description, a very clear impression of the value of concepts. Concepts are essential components of thinking, and understanding comes from the meaningful internal linking of relevant concepts. As White (12) puts it:

> "If people are said to understand a topic, this necessarily means that they possess many propositions about that topic which are highly interlinked through common concepts: Understanding may involve even more than that, but this extensive and organised body of facts is an essential component of it."

The term '<u>cognitive structure</u>' is commonly used (16) to describe the organisation of concepts in long-term memory. What Ausubèl (17) describes as '<u>meaningful learning</u>' is characterised as building new material into an existing cognitive structure. As we will describe later in more detail, various techniques have been suggested (18,19,20) for mapping cognitive structure.

We acquire concepts by <u>generalisation</u> (noting similarities or common properties) and by <u>discrimination</u> (noting differences).Hurd (15) gives a vivid description of the process:

> "Forming a concept is a searching process, exploring an unordered collection of facts for similarities and differences, for organisational properties and for a meaningful integration. In the process of abstracting a common property from a body of information, the student looks for logical relationships, invents constructs and tests them by noting which features characterise most of the data but do not represent other bits of information. The process is one of discriminating, categorising and evaluating in a cyclic manner, always seeking to get a better coding or arrangement of the data".

Young children discover the critical attributes of a concept (e.g. <u>dog</u>, <u>chair</u>) by the inductive process of <u>concept formation</u>. In the period of formal education, however, children acquire most concepts by a deductive process, which Ausubel (17) calls <u>concept assimilation</u>, in which "the critical attributes of concepts ..... are either presented to learners as a matter of definition or are implicit in the contect in which they are used". In this process, the use of <u>language</u> is particularly important.

> "When an individual uses language to acquire a concept, he is not merely labelling a newly learned generic idea; he is also using it in the <u>process</u> of concept attainment that transcends by far - in clarity, precision, abstraction and generality - the level of concept acquisition that can be achieved without the use of language"

In other words, language does not only permit us to 'label' concepts, and so make it possible to communicate and share our concepts with others. We use words to 'encode', 'manipulate' and 'store' the information. As White (12) has pointed out, "The vast body of information people carry in their heads is verbal information". Klausmeier et al (10) consider, at some length, the role of language in concept attainment. They conclude that, at the lower levels of concept learning, language may facilitate learning, but it is not a prerequisite condition since very young children can form concepts without language. Language plays a critical role, however, in attaining concepts at what they term a 'formal' level, at which "the individual must be able to discriminate and label all the defining attributes of the concept"

Each of us, of necessity, must form our own concepts. To that extent, concepts acquire idiosyncratic meanings. Concepts, as mental constructs, cannot be transferred literally from one person to another. On the other hand, we can talk about concepts and describe them in words. Word descriptions of concepts, such as are found in dictionaries, encyclopaedias and textbooks, represent what Klausmeier (10) calls the "societally-accepted" meaning of the concept.

Sutton (21) makes the interesting point that "the established tradition in science is that meaning can be expressed in precise definitions and that scientific knowledge is public and external, written down in journals. If, on the other hand, the 'meaning' of an idea is in its degree of connectedness within a structure of other ideas, then meaning is indefinitely expandable, is not in the information itself but in the learner's head, and differs from person to person. There are a multitude of different private versions of every science concept. Ideally they will have certain features in common which constitute the public, agreed, definable version."

In the study of mechanics, a 'concept' may mean different things. We may use the term 'concept' to indicate understanding of a word, e.g. the concept of a '<u>vector</u>'; to represent a group of related facts, e.g. the concept of '<u>acceleration</u>'; to represent an image of some kind, e.g.the concept of an '<u>elastic collision</u>' or occasionally to represent an area of knowledge,e.g. the concept of '<u>kinematics</u>'.

Concepts in mechanics differ in levels of abstraction and of complexity. At a low level of abstraction we have concepts such as '<u>length</u>' which are abstracted directly from experience and refer to a single attribute or property of the body. At a high level of abstraction we find such concepts as '<u>gravitational field strength</u>' which cannot be related directly to experience and which are defined by a relationship between other concepts. Hurd (15) has suggested that "concepts related to physical reality and which have substance in direct observation are likely to be easier to acquire than abstract ideas"

The complexity of a concept is given by its order. Thus <u>momentum</u> (mv) is a second-order concept but <u>kinetic energy</u> ($\frac{1}{2}$ mv^2) is a third-order concept. Lovell (22) comments that "while the levels of abstraction seem to be limited to three - for at the third level the pupil is no longer dealing with first-hand reality - the order of a concept may be any number depending on its complexity"

The particular concepts we are concerned with in this investigation are all at the third level of abstraction and are all at least second-order concepts. Lovell reminds us that "for the pupil, the real psychological difficulty lies in the formation of second-order concepts, that is, third level abstractions" (22)

The concepts we are concerned with are more properly called <u>principles</u>, since they are defined by relationships between concepts (e.g. force = mass x acceleration). A principle is more than simply a number of concepts linked in the same sentence. A principle (23) states a relationship between concepts which enables us to (1) predict consequences (2) explain events (3) infer causes (4) control situations and (5) solve problems. For example, a pupil might use the principle 'force = mass x acceleration' to

(1) predict that a mass will accelerate if an unbalanced force is applied,

(2) explain why the same applied force does not produce the same acceleration in different masses,

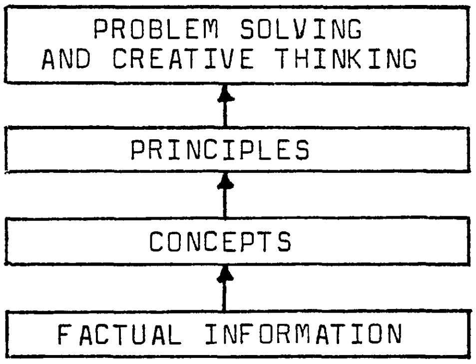
(3) infer that a mass will move at a uniform speed if the forces acting on it are balanced,

(4) cause a mass to accelerate by applying an unbalanced force,

(5) calculate the value of the force required to produce a given acceleration in a given mass.

It becomes clear that, at this level, the precise relationships involved in applying the principle require that the pupil has the capacity for abstract reasoning.

Gagne (24) emphasises that "to learn a principle, one must have previously learned the concepts of which it is composed". Learning the definition (the verbal statement of the principle) without an understanding of the prerequisite facts and concepts is, in Hurd's (15) words, "to acquire a fruitless verbalisation". Markle and Tiemann (11) comment that "verbalisations of the sort 'An X is ...' when asked a question 'What is an X?' are not reliable signs of a learner's grasp of a concept." The highest level of concept development is <u>problem solving</u> and <u>creative thinking</u>. At this level, the pupil can apply previously learned principles to problem situations. There is, as Goodwin and Klausmeier (25) suggest, a hierarchy of concept development.



There is a very similar hierarchical arrangement of facts → concepts → principles → laws → theories within the subject-matter. This is termed the <u>content structure</u>. (An obvious question arises - Is the content structure of the subject related in any way to the cognitive structure of concepts in long term memory?)

Osborne and Gilbert (26,27) have devised a method of investigating concept understanding in physics, which they call an '<u>interview about instances</u>' technique. They have reported on the potential and limitations of the technique, which turns out to have much in common with the technique used in the latter part of our own investigation. As we shall discuss later the main advantages of a technique like this may be its diagnostic function.

(b) Learning theories

There is no one theory of learning, neither is there a "well-defined strategy which assures every student will acquire a desired concept"(15).

Bruner (28) has observed that any theory of instruction must be concerned with three factors:

1. the nature of the knowledge to be learned;
2. the nature of the learning process;
3. the nature of the individual learner.

Lawton (29) and Karsh (30) have drawn attention to a list, produced by Hilgard in 1956, of fourteen points of general agreement for all learning theories. This list included the following:

1. In a learning situation the capacity of the learner is an important factor especially as regards age and ability

2. Motivation is an important factor in learning

9. Active participation by the learner is better than passive reception

10. Meaningful materials and tasks are mastered more easily

12. Information about good performance as well as mistakes aids learning

13. Transfer to new tasks will be better if the learner can discover relationships for himself and if he has experience of applying the principles involved.

Goodwin and Klausmeier (25) define learning as "a process inferred from relatively stable changes in behaviour that result through practice or interaction with, and adaptation to, the environment." Learning thus results primarily from experience and not from maturation, which involve changes that result primarily from physical growth. The term 'development' is commonly used to describe changes brought about by learning <u>and</u> maturation. Children are considered to pass through several stages or levels of cognitive development before reaching intellectual maturity.

Bruner (28) for example, describes the learner as moving through three <u>levels of representation</u>. In the <u>enactive</u> level, the learner manipulates material directly. He then progresses to the <u>iconic</u> level, where he deals with mental images of objects. Finally he moves to the <u>symbolic</u> level where he is strictly manipulating symbols. Although children develop enactive powers before iconic, and iconic before symbolic, Bruner suggests that, as mature adults, they will use all three. In any learning situation, Bruner suggests that the structure and form of the knowledge to be learned and the sequence in which the materials to be learned are presented should be matched to the ability of the learner. "Any idea or problem or body of knowledge can be presented in a form simple enough so that any particular learner can understand it in a recognisable form".

The structure of knowledge may be described in three inter-related ways: its mode of representation (i.e. enactive, iconic or symbolic); its economy (i.e. the amount of information we must have and work with to achieve understanding) and its power (i.e. its capacity for enabling new connections to be made). For example, the symbolic formula "$s = \frac{1}{2} gt^2$" is both more economical and more powerful than the original data involving distances, times and gravitational constants. To 'understand' such a formula, however, the learner must start with the original data and gradually work towards the abstract relationship.

Motivation of the learner and reinforcement in terms of 'knowledge of results' are also stressed by Bruner. It is important, in learning a discipline, that the learner builds, in his mind, a 'coherent conceptual structure' and is 'actively involved in erecting and adapting tbis structure'. The importance of active involvement has led Bruner to advocate 'discovery learning' as a general teaching method. Shulman (31) describes Bruner's technique as "providing contrasts and incongruities in order to get the child, because of his discomfort, to try to resolve the disequilibruim by making some discovery (cognitive restructuring) .... For Bruner, instruction is a roller-coaster ride of succcessive disequilibria and equilibria until the desired cognitive state is reached or discovered .... He has a pupil begin with <u>problem solving</u>. This process is analogous to teaching someone to swim by throwing him into deep water. The theory is that he will learn the fundamentals because he needs them".

Bruner (28) has claimed that "a theory of instruction is concerned with how what one wishes to teach can best be learned, with improving rather than describing learning ..... We teach a subject not to produce little living libraries on that subject but rather to get the student to .... take part in the process of knowledge - getting. Knowing is a process, not a product".

Perhaps the most well-known sequence of stages of cognitive development is that outlined by Piaget, which is as follows:

0 - sensory-motor (birth to 2 years)
1 - pre-operational (2 to 7 years)
2 - concrete operational (7 to 12 years)
3 - formal operational (12 years to adult)

Only the latter stages (2 and 3) are significant in secondary education.

During the concrete operational stage, pupils gradually acquire the ideas of conservation of substance, length, weight, number, volume. They become able to group objects together on the basis of similarities and differences and to arrange objects in a graded sequence. They cannot, however, handle abstractions or hypothetical propositions. They tend not to plan ahead, often work by trial and error, and have difficulty with verbal definitions.

The formal operational stage sees an increasingly free use of hypothetical reasoning and ability to handle abstractions. They now seek exhaustive definitions and general rules. They can plan ahead, make and test hypotheses, use symbols and become able to carry out operations on principles rather than on concepts.

"With the coming of formal operational thought, the pupil can begin to understand in an analytic, rather than an intuitive, sense such concepts as momentum and energy .... An understanding of these ideas, as the physicist wants them grasped, demands the elaboration of precise relationships between other quantities; an intuitive understanding does not"(32)

Lovell (32) has outlined the methods used in studies by Archenhold (33) on potential energy and Williams (34) on momentum. In each case there appears to be a definite hierarchical order of concepts involved. For example, the sequence for momentum would appear to be:-

"(i) $p = mv$ and simple calculations by rule.
(ii) 'Σp = constant' type problems.
(iii) 'Σp = zero' type problems, with an intuitive idea of directional property.
(iv) $F = \Delta p/t$ (where t = time) to simple calculations not involving the vector nature of p.
(v) Σp = constant, in terms of $F_1 = -F_2$ and $F = \Delta p/t$
(vi) Vector nature of p revealed in calculations of Δp and Σp = constant. " (32)

This sequence was arrived at by comparing the mean scores on sub-tests.

Raven has investigated the development of the concepts of acceleration (35) and momentum (36) by giving the pupil a range of tasks and analysing the results. He concluded that children at the concrete operational level could develop an intuitive idea of these concepts, but the psychological order of the tasks differed from the logical order.

The work of Piaget has been largely devoted to examining how the basic concepts of mathematics and science develop, for the most part at the stage of concrete operational thought Peel (13) comments that "science concepts, in the main, are 'relational concepts', which consist of common relationships between the features of different experiences .... We do not know enough about the process (of concept formation) in adolescence".

Reviews of Piaget's work are given by Lovell (32), Peel (13) and Floyd (37).Driver and Easley (38) have provided a critical analysis of Piaget's work and suggest that "a series of replication studies which focused more on the actual content of the pupils' ideas and less on the supposed underlying logical structures would be useful".

Piaget's work has been too often interpreted in a negative way in the sense that it tells us what not to do at certain ages and stages. Shayer (39), for example, has estimated the conceptual demands made of a pupil by each topic in the Nuffield O-level Physics course in terms of Piagetian stages of development. He concluded that "the course as it stands and is intended to be handled as a five-year process, is accessible at all points only to the 125+ I.Q. range of pupils". Using a group testing technique Shayer et al (40) have studied the distribution of Piagetian stages of thinking in a sample of 10,000 children and their results indicate that, between the ages of 12 to 14 years, only about 10% to 20% of the population are capable of abstract thinking although perhaps 50% to 80% will be fairly advanced 'concrete' thinkers. The apparent mismatch between the conceptual demands of the curriculum and the stage of conceptual development of the pupils may be remedied by what is called 'cognitive acceleration'. In this way, Shayer hopes to "influence the cognitive development of children so that they would become capable of using the high level material that we think it necessary to teach" (41). This technique is currently being investigated.

Robertson and Richardson (42) have investigated the developmental sequence by which pupils between 12 and 16 years acquired a number of physics concepts (such as pressure, force and work). They note particularly the pupils' lack of understanding of such concepts. "The tests of the conservation of pressure, force, acceleration work and potential energy provide dramatic evidence on the lack of understanding of these concepts .... There is much evidence of verbal learning."

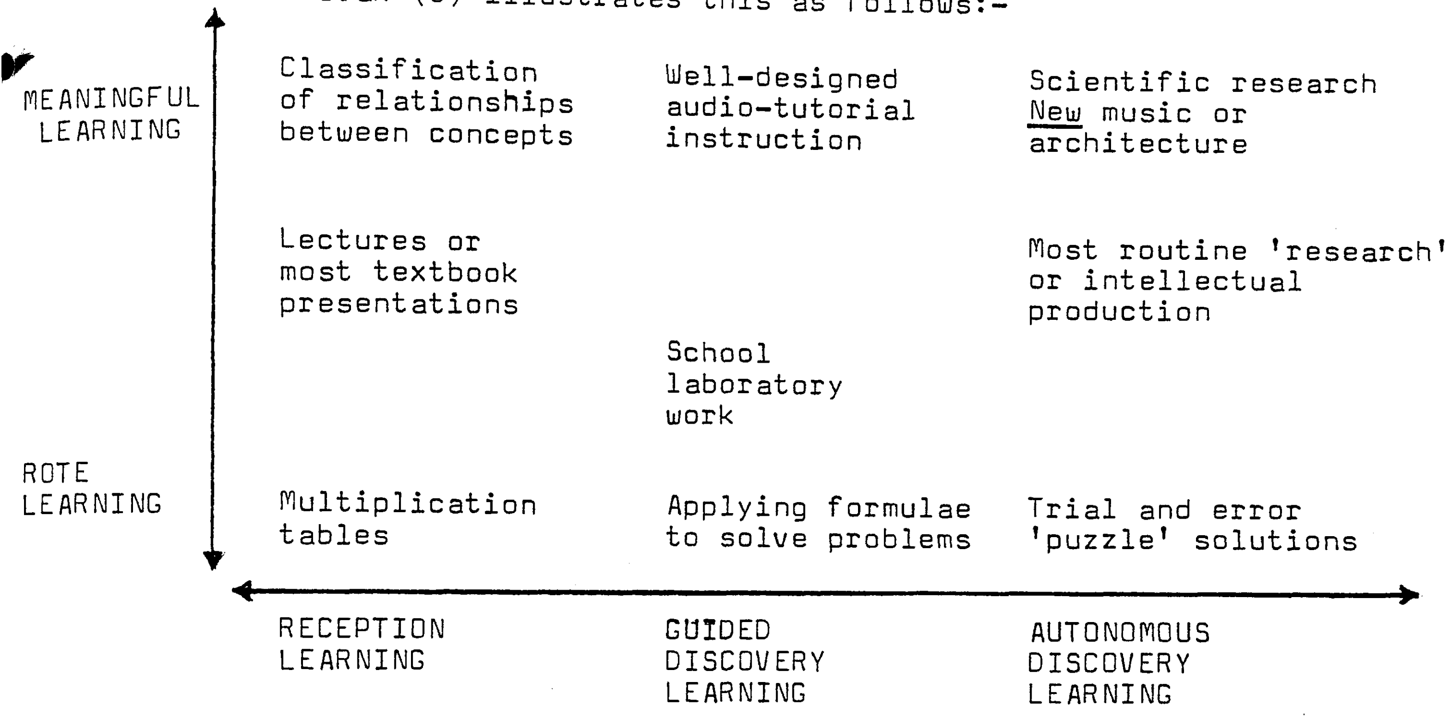
Novak (8) argues the case for an alternative to Piagetian psychology for science and mathematics education. Having described various research findings, he concludes:

"We see no evidence of 'stages' of cognitive development over the age range six to twenty plus, but rather evidence for cognitive development manifested as a broadening array and elaboration of specific concepts. To the extent that broad, widely relevant concepts are differentiated over time, older subjects show more facility for learning new relevant concepts and hence a generalised increase in competence for abstract reasoning is manifest .... The data presented in this paper support, in our view, a model of cognitive development that is not 'stage' dependent, but rather dependent on the framework of specific concepts and integrations between these concepts acquired during the active life-span of the individual. The learning processes involved are adequately explained both for contemporaneous learning episodes and developmentally over time by Ausubel's theory of cognitive learning".

A basic premise of Ausubel's theory of learning is that 'the most important single factor influencing learning is what the learner already knows' (8). This '<u>prior knowledge</u>' influences the process whereby the learning occurs. The importance of prior knowledge to the learning of science, in terms of Ausubel's theory, has been discussed by West and Fensham (43).

Two fundamental dimensions of the learning process are involved in Ausubel's theory. One dimension relates to the ways information is made available to the learner - either by <u>reception</u> or by <u>discovery</u>. The other dimension relates to the means - either <u>meaningful</u> or <u>rote</u> - by which the learner assimilates the information into his existing cognitive structure.

These two dimensions are assumed to be independent. Novak (8) illustrates this as follows:-



In reception learning, the material to be learned is presented, in its final form, to the learner. In discovery learning, not all the information to be learned is provided; some must be identified by the learner. Ausubel's theory applies mainly to reception learning, since, in his view, most concepts are learned by concept assimilation rather than concept formation (17). Ausubel has queried the advantages claimed for the 'discovery' approach (44) and has argued that unstructured autonomous discovery learning for a pupil of average ability is unrealistic. Meaningful verbal learning (as distinct from rote learning) is a more efficient method of transmitting knowledge.

"Meaningful learning takes place if the learning task is related in a non-arbitrary and non-verbatim fashion to the learner's existing structure of knowledge" (17) This assumes the learner makes a conscious effort to relate the new knowledge to existing concepts or principles in his cognitive structure and that the new knowledge is potentially meaningful to the learner. Rote learning will occur if the learner lacks relevant concepts in his cognitive structure or if he decides to internalise the new knowledge in a verbatim fashion.

The conditions for meaningful learning has been summarised (44) as follows:-

Cognitive structure has relevant items (subsumers)	+	New material to be learned is logically relatable	+	Learner is disposed to relate ideas this way

Meaningful learning involves the interaction between the new knowledge and existing knowledge. Ausubel uses the term 'subsumer' to identify any concept or principle which the learner already knows that can provide an anchorage for the new knowledge. In the process of 'subsumption', both the anchoring concept and the new knowledge are modified but retain their separate identities. The new knowledge is assimilated into the cognitive structure which, as a result, becomes more elaborated with new interconnections between concepts. Meaningful learning, therefore, results in the continuous modification and elaboration of the learner's cognitive structure, and individual variation in concept attainment is a function of the specific learning experiences rather than maturation. "Older children are generally capable of solving more complex (abstract) problems than younger children not because they have some unique cognitive capacity (structure) but rather because the overall level of differentiation and integration of their concepts is much more elaborate" (8)

If meaningful reception learning involves the assimilation of potentially meaningful material into the learner's existing cognitive structure, it follows that successful assimilation of new concepts will depend on the "content, stability, clarity and organisational properties" of the learner's existing cognitive structure - his '<u>prior knowledge</u>' .

"The major implication of all this for teaching concepts is that inasmuch as existing cognitive structure reflects the outcome of all previous meaningful learning control over the accuracy, clarity, longevity in memory and transferability of the concepts to be assimilated can be exercised most effectively by attempting to influence the crucial variables of cognitive structure" (17)

Ausubel suggests that this could be achieved in two ways

(a) by the use of 'unifying' concepts
(b) by appropriate sequencing of the material.

Ausubel advocates the provision of '<u>advance organisers</u>' - general expository or comparative statements which are presented to the learner <u>before</u> the more detailed new material, and which facilitate learning by providing a framework into which the new knowledge can fit and, at the same time, linking it to existing knowledge. It is this linking or bridging aspect of the organiser which is most useful to the learner. Ausubel (17) suggests that an organiser should be "presented at a higher level of abstraction, generality and inclusiveness", but Novak (8) points out that "where no relevant concepts exist in the learner's cognitive structure, it is unlikely that any type of advance organiser will function, for the organiser itself must be meaningful to the learner".

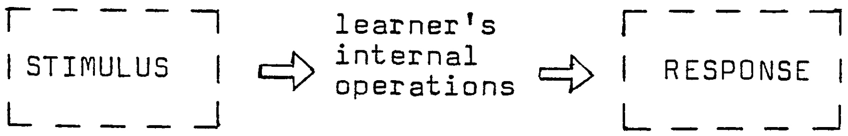
The idea of advance organisers has been the most researched part of Ausubel's theory (45,46,47) but, as Novak (8) points out, most studies have not satisfied the conditions for meaningful learning. Westand Fensham (43) suggest that "in attempting to establish (the) effectiveness (of Ausubelian procedures in classrooms), research might begin in learning areas that are acknowledged to have high levels of failure".

Ausubel's theory relates to the cognitive process of learning complex verbal material and, as such, has direct relevance to the teacher. The importance of <u>prior knowledge</u> in influencing subsequent learning suggests that diagnostic or 'readiness' tests to provide evidence of existing cognitive structure (and possible misconceptions) might be useful. To facilitate learning, the teacher should make use of frequent references to previously learned material and, at the beginning of a lesson, or new part of the course, to the learning which is to follow. The use of 'unifying' concepts, of wide explanatory power, and the explicit linking of common ideas should help to promote meaningful learning.

The theories of learning so far described concentrate attention on what goes on in the mind of the learner. They would all see learning as the internal reorganisation of existing knowledge to accommodate some new idea. They would agree that "cognitive development is a dynamic process and that cognitive structure is constantly being modified through experience". Their model of the learning process might be (25):

stimulus ⇨ LEARNER'S INTERNAL OPERATIONS ⇨ response

The behaviourist theory of learning, on the other hand, pays much more attention to the association of a given stimulus and a response. From the actual observed changes in behaviour of the learner, they infer that learning has taken place. Since they cannot see into the learner's mind they argue that they can only determine the state of his intellect by observing some aspect of behaviour. By feedback of information to reinforce the desired behaviour pattern, they would claim to promote learning. Their model of the learning process would show a different emphasis (25):



When this theory is translated into practice, the difference in emphasis becomes more apparent. The behaviourist philosophy is that instruction is teacher controlled (or even subject matter controlled) and the learner is carefully guided through a prepared sequence of steps towards a previously defined terminal objective, stated explicitly in behavioural terms. The instructional sequence is logically, rather than psychologically, structured and is based on a task analysis of the material to be learned.

The influence of the behaviourist theory of learning is seen in the extensive work which has been done on the writing of behavioural objectives (48,49), and in the development of programmed learning and computer assisted instruction (9,30). A more direct application to the learning process has been the idea of '<u>learning hierarchies</u>', developed by Gagne (24).

Gagne, in his book '<u>The Conditions of Learning</u>' identifies eight types of learning which can occur. Arranged in a hierarchical order, they are:-

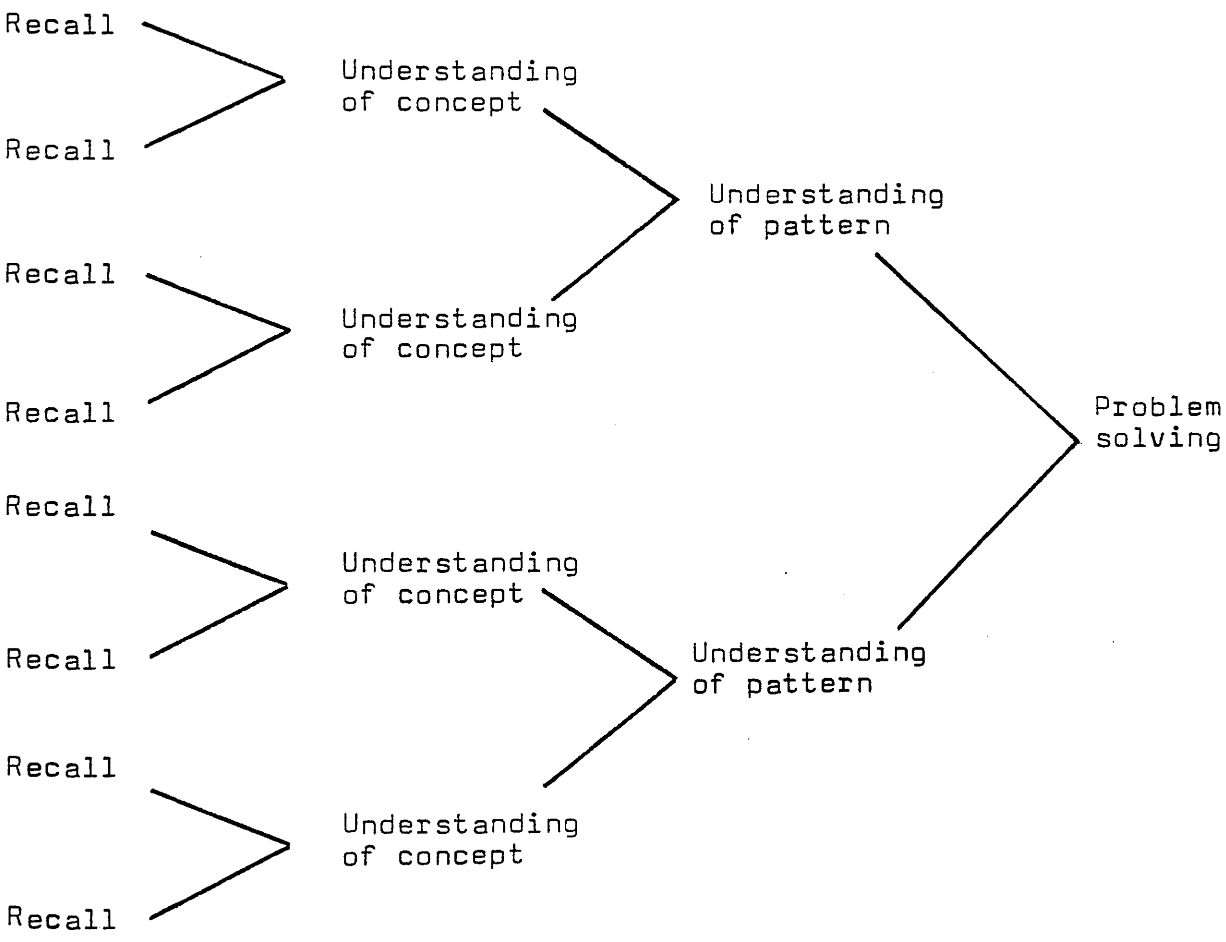
1. signal learning
2. stimulus - response learning
3. chaining
4. verbal association
5. multiple - discrimination learning
6. concept learning
7. principle (or rule) learning
8. problem solving

The highest ability - problem solving - requires that the learner has progressed through all the the previous stages. All the others become 'prerequisites' for problem solving. In the same way, Gagne argues, any piece of knowledge can only be acquired by people who possess certain prerequisite pieces of knowledge, which have their own prerequisites in turn.

> "Thus it becomes possible to 'work backward' from any given objective of learning to determine what the prerequisite learnings must be - if necessary all the way back to chains and simple discriminations. When such an analysis is made, the result is a kind of map of what must be learned. Within this map, alternative 'routes' are available for learning, some of which may be best for one learner, some for another. But the map must represent all the essential landmarks" (24)

The end product of such a task analysis is a learning hierarchy. The desired terminal behaviour appears at the top of a complex pyramid of subordinate prerequisite tasks and, at the base of the pyramid, appear the skills which the learner already has - his 'prior knowledge'. According to Gagne, the learning process should be sequenced in accordance with the prepared learning hierarchy, for this represents the logical sequence of steps. This view is shared by White (50) who, more recently (12) has drawn attention to "a substantial body of research which shows that intellectual skills (i.e. concepts and principles) are learned hierarchically .... learning hierarchies are powerful tools which teachers can employ for achievement of intellectual skills". (In earlier articles, White (51) had criticised Gagne's work on learning hierarchies on methodological grounds and had proposed (52) more exacting validation techniques.)

Hall (53) shows, by means of a diagram, how Gagne's ideas have directly influenced the Schools Council Integrated Science Project (S.C.I.S.P.)



A learning hierarchy is meaningful to a person who has already mastered the learning, and will almost always reflect the logical structure inherent in the content of the material. However, the empirical validation of a proposed hierarchy (3,51,54) can cause problems since "the facts, concepts and principles the learner uses for subsumption may not be those obtained by a logical task analysis undertaken by someone who has already mastered the learning" (43)

Airasian (54, 55) has proposed '<u>ordering theory</u>' as a method of validating learning hierarchies, to allow for alternative sequences.

Preparing a learning hierarchy is relatively straightforward. The task analysis involved in preparing a learning hierarchy can be of value to the teacher, since it makes explicit the inter-relationships between the subordinate concepts and principles. The completed hierarchy can be used as a check-list to ensure that, in teaching the concept or principle, no essential steps in the sequence are omitted. This, we believe, is what Rae et al (3) had in mind when they recommended the construction and use of learning hierarchies in the teaching of physics.

All the learning theories we have described have stressed, to a greater or lesser extent, three important features of the learning process.

(1) <u>The content structure of the material</u>

Gagne has emphasised the hierarchical ordering of concepts and principles, Bruner has emphasised the structure of knowledge and Lovell and Shayer have related difficulty level to Piaget's developmental stages of learning.

(2) <u>The cognitive ability of the learner</u>

Gagne and Ausubel have both emphasised the importance of prior knowledge in providing further learning. Bruner and Ausubel have interpreted learning as the continual modification and restructuring of the learner's cognitive structure, Bruner and Piaget have stressed the developmental levels of cognitive ability.

(3) The learning experience

All the theories have emphasised the importance of correct sequencing. Ausubel and Gagne have favoured an expository teaching style, while Bruner has opted for discovery learning. All of them have stressed the need for the learner to be actively involved in the learning process, to be motivated, and to receive reinforcement in the form of knowledge of results.

In a sense, we are back at our original list of generally agreed points, given on page 19.

The rote learning of concepts and principles in science is not uncommon. To remedy this situation and encourage more meaningful learning, we require to achieve a better match between the material to be learned and cognitive abilities of the learners. This may be approached from three separate directions:

(1) The material to be learned

We should consider the material to be learned from the viewpoint of the learner and, by the use of expository and comparative 'organisers', try to make the material as potentially meaningful as possible. Learning hierarchies will help us to appreciate the detailed structure of the material and will highlight relationships between concepts. They will not, in general, prescribe the optimum teaching sequence.

(2) The teaching method

In teaching the material, we should endeavour to relate new material to existing knowledge and make use of all possible methods (e.g. concept definition, synonyms, verbal cues to relevant attributes, sentences using concept names and many instances and non-instances of the concept (10))to facilitate concept attainment. The teaching sequence may be critical, as may be the use of frequent questions. Giving the learner ample opportunity to use the concept or apply the principle in a wide variety of situations should help, as should encouraging the learner to evaluate the adequacy of his own concepts.

White (12) gives some good practical suggestions regarding teaching method, including lesson structure, questioning, and using different levels of definition. He is critical of formalised laboratory work and over-use of demonstration experiments.

(3) The learner

Diagnostic 'readiness' tests should be devised to check on the learner's prior knowledge and to identify misconceptions or 'alternative frameworks' (38) which can interfere with subsequent learning. Where necessary, appropriate remedial teaching should be given. 'Cognitive acceleration' (41) should be encouraged.

Of the learning theories considered, the most useful theory for describing the learning of complex verbal material would appear to be that of Ausubel, although Gagne's ideas are also useful.

(c) Mapping cognitive structure

"Cognitive structure is a hypothetical construct referring to the organisation (relationships) of concepts in memory" (20). Meaningful learning, according to Ausubel, involves the relating of new knowledge to existing concepts in the learner's cognitive structure. This suggests that it would be useful to be able to 'map' the learner's cognitive structure. We now consider how this might be accomplished.

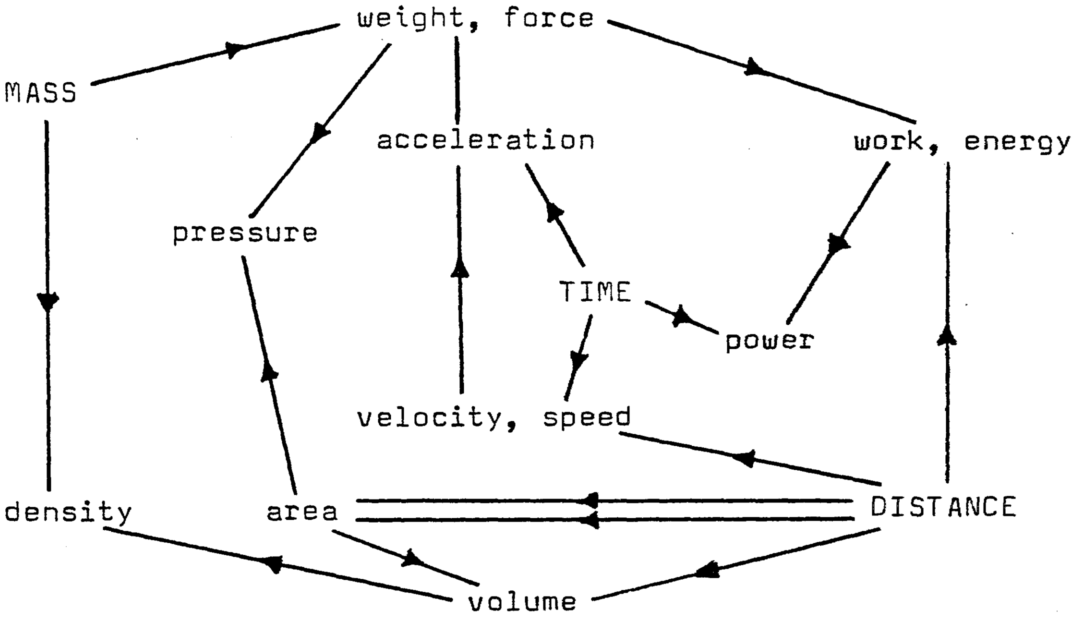
Preece (18) makes an important point that "in mapping cognitive structure, the aim is to obtain structural information about the internal representation of concepts. The concern is with the second-order structure involving the relations among concepts ... rather than the first-order structure within (concepts)" In other words, it is the relationships between the concepts that are examined, not the concepts themselves. This could be a limitation of the method, if we are particularly interested in the understanding of individual concepts.

Various techniques (20, 57) exist for mapping cognitive structure, but they all start from word association tests, using 'concept labels' (e.g. force, momentum, work) as stimulus words. It is claimed that, in studies involving scientific concepts, the word association technique has advantages over the problem-solving approach.

In the continued word association test, in which the subject provides a number of associations to the stimulus word, the degree of overlap in response hierarchies is a measure of the 'semantic proximity' of the stimulus words. Garskof and Houston's (58) relatedness coefficient, which allows a differential weighting of associations in order to reflect the greater importance attached to earlier responses, is a widely used measure of overlap.

Preece (18) reports that "the most well-developed theories of semantic (long-term) memory involve graphic or network models in which the nodes represent concepts and the links between nodes represent conceptual relations".

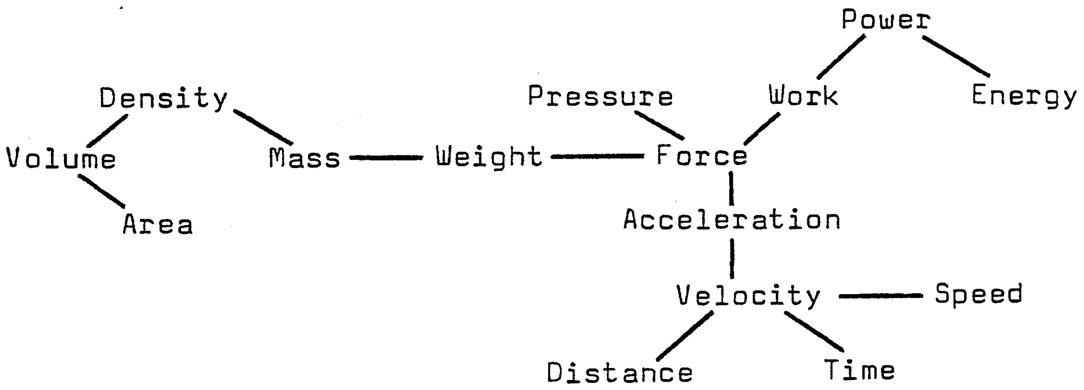
Most research on the organisation of scientific concepts in long-term memory has been confined to concepts in mechanics (59-64). This is perhaps a consequence of the facts that the number of concepts in mechanics is limited and, more importantly, that there is a very well-defined content structure in mechanics, and each concept may be defined in terms of three basic concepts, mass, distance and time. This is illustrated in the digraph model of the set of mechanics used in a study by Preece (60).



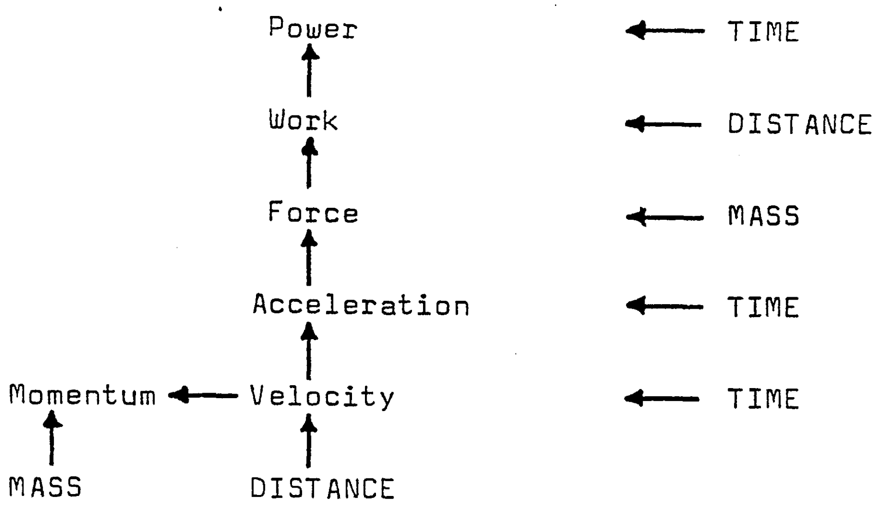
Johnston et al (61), using physics students as subjects, found that a three-dimensional model best described their cognitive structure for the concepts of power, work, force, momentum, acceleration and velocity.

Shavelson (59), using high school students as subjects found four main clusters of concepts. Cluster 1 included the concepts force, work, power and energy; cluster 2 included mass and weight; cluster 3 included distance and time and cluster 4 included velocity, speed and acceleration. He concluded that during instruction the students' cognitive structure changed considerably. "The cognitive structure of the instruction subjects corresponded more closely to the content structure at the end of instruction than at the beginning; no similar change was observed in the control group.

Preece (60) reports that, for physics students covering the whole period in which physics is taught at school and university, he has obtained spatial maps of mechanics cognitive structure. "The maps of all the groups were dominated by three concept groupings - a kinematics cluster (e.g. *velocity*, *distance*, *time*), a statics cluster (e.g. *weight*, *mass*, *density*) and an energy cluster (e.g. *energy*, *power*) .... For the most knowledgeable groups, the concept *force* took up a central position between the energy and statics clusters."



Johnston et al (65), using university physics students as subjects, showed that the following hierarchical model, in which the concepts MASS, DISTANCE and TIME formed the base from which the hierarchy was constructed, was a good representation of the students'cognitive structure.



Preece (60) also has noted that "the cognitive structures of the most knowledgeable groups were particularly well represented by the hierarchical model, and this underlines the psychological (as distinct from logical) importance of Gagne's learning hierarchies".

Most modern physics textbooks use the S.I. system of units, in which the basic units, for mechanics at least, are mass (kg), length (m) and time (s). For younger children, these are not 'ostensive' concepts. Robertson and Richardson (42) have shown that time is not a first-order concept. "Time is more removed from reality than speed". Preece (60) has commented that "for the least knowledgeable groups, the models based on the density - distance - velocity triad gave a better fit to the data"

It would appear, from these results, that, as pupils study mechanics, their cognitive structure approximates more and more to the logical content structure, based on the three fundamental concepts of mass, length and time. Moreover, "the cognitive structure of mechanics for those knowledgeable in physics is quite similar to the organisation of concepts in a learning hierarchy" (60) Thus there may well be some direct benefit to be gained by giving pupils the logical content structure in the form of a learning hierarchy, in the sense that it may provide the necessary framework to promote meaningful learning. Obviously this would not function as an 'advance organiser' but one could envisage the content structure being gradually built up as a hierarchy as each new concept is introduced.

We have some reservations about the value of word association tests. They only sample 'verbal learning' and concentrate on the formal 'definitions' of the concepts. Conceptual understanding involves discrimination as well as association. It also involves being able to use the concept or principle in problem solving.

Sutton (19) makes the very obvious point that "word association tests have been used principally in relation to the static aspects of 'the library' - organisation of information in long term memory. It is unlikely to reveal the dynamic aspects of mental organisation. To discuss these, some observation of the person in the act of problem solving seems necessary ... To describe these on paper would perhaps require a flow chart, or something nearer to a computer program"

Sutton also discusses other techniques which have been used in attempts to probe the learner's cognitive structure. These are the clinical interview, the selection of a preferred statement from several correct ones (i.e. the idea of '<u>cognitive preference</u>'), and the rating of a concept in terms of its position on some sort of continuum (i.e. the idea of '<u>semantic differential</u>')

More detailed descriptions of cognitive-preference testing are given by Jungwirth (66,67), Tamir (68) and Van den Berg, Lunetta and Tamir (69). In brief, the technique assumes that the learner may use one of four modes of 'cognitive preference' when processing scientific information. He may accept it for its own sake (i.e. recall mode) or because it explains some scientific principle (i.e. principles mode) or in view of its usefulness in a more general context (i.e. application mode) or he may critically question the information (i.e. questioning mode). The latter modes of responding, it is claimed, would indicate a more complex cognitive structure and, as the learner's grasp of the concept improves, we would expect his preferred mode of responding to move away from the recall mode towards the questioning mode.

(d) Information overload

Why, despite teaching, can the learner not grasp a concept?

Wilson (70) has suggested the following possible reasons.

(i) He is being wrongly taught (e.g. the teacher is not proceeding slowly enough from the known to the unknown, is not giving enough examples etc.)

(ii) He lacks the necessary 'prior knowledge'

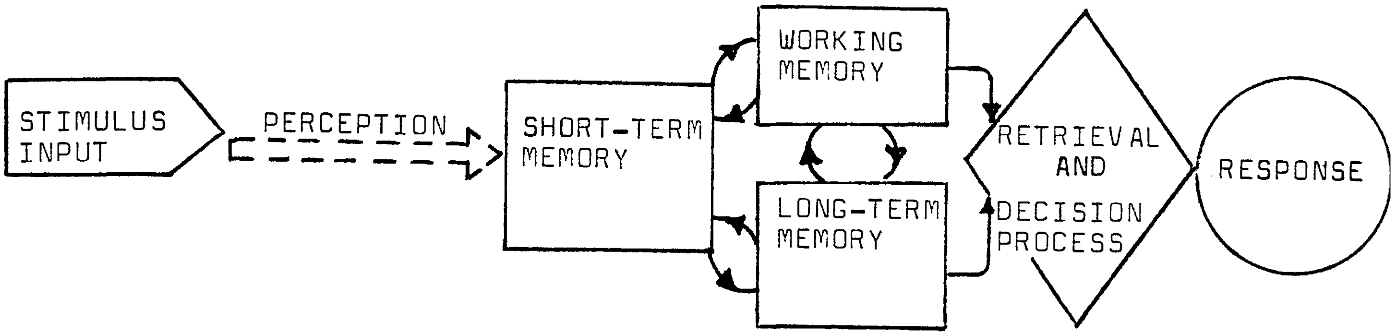
(iii) The concept is governed by so many rules that he cannot keep them all in mind at once. By the time the teacher is explaining the last he has forgotten the first.

(iv) There is a sense in which he resists learning (an 'emotional block'?)

(v) There is something deficient in his brain.

(vi) He cannot or will not concentrate sufficiently to learn.

We want, in this section, to consider particularly Wilson's point (iii). We start by considering Shavelson's (20) model of how we process information.



"The information processing model can be divided into two general components: <u>perception</u> and <u>memory</u> .... The memory component is closely related to our definition of cognitive structure ... Memory can be characterised by four subcomponents .... <u>short-term memory</u> is a small capacity memory which serves as a buffer between both <u>working memory</u> .... and <u>long-term memory</u> - an unlimited capacity, highly organised, permanent information store. The <u>retrieval and decision process</u> permit us to search and retrieve information."

Information is stored in long-term memory, according to White (12), as <u>verbal knowledge</u> (facts), <u>intellectual skills</u> (concepts, and principles) and <u>images</u>. Shavelson (20) describes it as "an extremely complex network" in which modes represent concepts and the links between nodes represent relationships between concepts. The learner's cognitive structure is assumed to be located in long-term memory.

Working memory, as the name suggests, is important in problem solving behaviour. The problem is observed and translated and passed to the working memory. Long-term memory is then searched for relevant relationships to modify the structure in the working memory and so arrive at the solution to the problem. In computer terms, working memory is the 'central processing unit' (C.P.U.)

In the same way, short term memory is the 'input buffer file' with a very limited storage capacity (7 ± 2 separate bits of information) (71). The capacity of working memory is more than this, but not much more. Long term memory has limitless capacity and would be analogous, in computer terms, to the 'floppy disc'.

The problem arises when, as described above, the number of separate bits of information overloads the capacity of the short term memory buffer, and some is lost, the learner has 'forgotten' the beginning.

The remedy lies in 'chunking' (72) the information. Johnstone (73) defines a 'chunk' as "what the observer perceives as a unit, for instance a word, a letter or a digit." To take a simple example a telephone number (041-339-8855) is much more easily processed as three 'chunks' rather than ten separate digits.

Johnstone (74) suggests that there is a fundamental connection between information content, the state of conceptual development and the perceived level of difficulty. This can be summed up as follows.

" (1) The <u>number of units</u> represented by the information will depend upon the <u>conceptual understanding</u> i.e. if you understand something, you can group pieces into chunks more efficiently

(2) The <u>larger the number of chunks</u>, the <u>more difficult</u> the material will seem to be and the <u>poorer</u> will be the results.

(3) If the chunk <u>capacity</u> is exceeded, two possible results will appear

   (i) the pupil <u>will extract no useful information</u> if he tackles it as a whole, or

   (ii) if he has some <u>memory saving strategy</u>, which allows for <u>sequential treatment</u>, he may succeed.

(4) Conceptual understanding leads to an efficient (small number of chunks) organised (sequenced) and converging strategy " (74)

The implications for the teaching situation are clear.

(1) When introducing a concept or while it is still developing, the information content should be kept low.

(2) Redundant, irrelevant information should be kept well out the way during the development of a concept. The learner may well assume the irrelevant information is essential.

(3) In cases where the information content is necessarily high, due to the nature of the material, then either postpone the introduction as long as possible or provide some 'rule of thumb' to permit the material to be chunked.

Information content includes unfamiliar words, pieces of apparatus, mathematical calculations and the like which may be very familiar to the teacher. To quote just one example - the ticker-timer was introduced as a simple piece of pupil apparatus to enable experiments on Newton's laws of motion to be performed by pupils. Unfortunately experience has shown that pupils have very great difficulty in analysing the resulting ticker tape. Many schools have now adopted the more expensive, but more easily read digital electric stopclocks. The latest version of these uses 'micro-chip' technology to display velocity and/or acceleration directly as well as elapsed time (75).

(e) Some further relevant research

In this final section, we report on some research findings which may not relate directly to concept learning, but, in our opinion, may be very relevant when it comes to interpreting results, or to devising new ways of assessing conceptual understanding.

We came across several references to studies of pupils' misconceptions in science. For example Doran (76) studied common misconceptions related to the kinetic theory by 7-12 year old pupils. Za'tour (77) studied misconceptions in areas of physics, earth science, chemistry and biology among university students in Lebanon.

Viennot (78) reports that the ideas of 'intuitive physics', however wrong they may be, resist attempts to change or modify them. "Spontaneous reasoning is highly robust and outlives teaching which contradicts it"

Lebout-Barrell (7), in a study of high school and university students, found misconceptions (or 'preconceptions') related to force and motion which remained after formal teaching. "The child's commonly held dictum is that a body falls when its mass - and consequently its weight - is greater. The introduction of the concepts mass and weight has changed neither the reasoning nor the conclusion".

The problem appears to be that the pupils have been given the formal models or theories but have assimilated them wrongly. In Ausubel's terms, they have failed to relate, in a meaningful way, the new knowledge to their existing knowledge. Their existing preconceptions are interfering with the assimilation of the new knowledge.

Driver and Easley (38) have suggested the term 'alternative frameworks' for the pupil's own self-consistent, conceptual structures which are distinct from 'misconceptions' but may differ from the formal scientific explanations. Entwistle and Huggins (79) have reported that, when two closely related concepts are taught together, the pupils learn less about either concept than they would if the concepts were presented separately or alongside some unrelated concept. The close association between the concepts appears to interfere with the meaningful learning.

Larkin and Reif (80) have investigated the problem solving ability of university students. They recommend that students should be taught to (a) integrate separate principles into a general coherent method suitable for many diverse problems and (b) to approach the problem hierarchically by a process of successive refinements.

Whitaker (81) argues that, with Newtonian mechanics problems, greater stress should be laid on the basic concepts and less on an empirical problem solving technique.

We noted references to a teaching method called structural communication (82,83,84). This appears to have great potential both as a diagnostic method of identifying and correcting common conceptual errors and, more importantly, of bringing out the structure of the learning materials. It has been described as 'an interactive system for teaching understanding'. The authors claim that by emphasising structure, they can transmit an understanding of the relationships between facts as well as a knowledge of the facts themselves. White (12) has described the technique; and comments that "where verbal knowledge is to be acquired, it is a powerful method ..... There should be little difficulty in adapting it to intellectual skills" We will describe later how we used this technique, at least in part, in our investigation.

As our own investigation into conceptual understanding progressed, we became more and more conscious of the need to have some effective, diagnostic measure of the pupil's conceptual understanding. This, we considered, should be criterion-referenced rather than norm-referenced and we obtained a great deal of useful information from Brown's (85) review of criterion-referenced assessment. We will make more detailed reference to this source in a later chapter.

CHAPTER 3 - THE TEACHER QUESTIONNAIRE

Introduction

In chapter 1, we described how the topic for the present research investigation arose as a direct consequence of a preliminary study of concepts of physics, carried out by Johnstone and Mughol (1) in 1974-76. In this, and the following chapter, we will describe and discuss the results obtained from two separate but related pieces of exploratory research we carried out during 1977-78, as a necessary preamble to the main investigation, which did not start until early 1979.

The previous research had indicated that "a number of concepts traditionally introduced into elementary physics courses are proving troublesome" (1) It will be recalled that the area of mechanics, involving in particular such concepts as momentum, conservation, elastic and inelastic collisions, energy and power, seemed to be a general area of difficulty, and it was therefore decided to investigate this area in more detail. Since we had some personal reservations about certain points of detail in the previous research study, we thought it pertinent to carry out a preliminary general investigation of the area before embarking on the detailed study of the specific concepts involved.

Our preliminary investigation involved the collection and analysis of empirical data from two separate sources:

(a) By means of a detailed questionnaire, we sampled the opinions of experienced teachers of physics as to what specific concepts and principles were essential to the understanding of mechanics.

(b) By means of two specially constructed multiple-choice tests, which sampled the various types of problem the pupil might encounter in a study of mechanics, we investigated the pupils' ability to solve such problems.

The present chapter will describe the information we obtained from the teacher questionnaire. The data obtained from the pupil tests will be described in Chapter 4.

A closer look at some points of detail from the previous study

We do not dispute the validity of the findings reported by Johnstone and Mughol. We have some reservations, however, about some points of detail. We were a little concerned, for example, that more than half of the topics, which appeared on the list of topics used in the subjective assessment of difficulty, required the provision of some explanatory wording. For example:

1. Particulate nature of matter (everything is made up of particles)

5. Idea of uniform motion (body can maintain uniform motion without some unbalanced force to keep it moving)

20. Idea of induction: (i) electric (e.g. charging an electroscope by induction), (ii) magnetic (production of temporary magnets), (iii) electromagnetic (production of a current in a circuit when change in magnetic flux)

We wondered what effect these explanatory phrases had had on the '<u>index of difficulty</u>' which the authors used as an estimate of the perceived difficulty of a topic. More importantly, we wondered why such explanatory phrases had been provided in some, but not all, the topics on the list, and on what basis it was decided that such phrases were required, for example, to help explain 'uniform motion', but were not required to help explain 'pressure'. Also, as in the case of topic (20) quoted above, does the provision of the explanatory phrases not make it induction subjectively more difficult, by 'spelling out the details'. We could envisage the pupil thinking he 'understood' induction, for example, until he saw exactly what such an understanding was considered to involve.

Such comments, of course, do not invalidate the overall observed pattern of results since they would apply to all three groups tested. We have little doubt that there would still be common peaks of difficulty, but perhaps these peaks would not be so extreme in either direction. We would anticipate that the three graphs would still show a marked similarity and would still show the same general trend in that the 'university line' would lie below the 'fifth-year line', which in turn would lie below the 'fourth-year line', as shown in Figure 1 on page 2.

Our concern about the wording of the 'topics' on the original list became more specific when we looked at the 'index of difficulty' for the topics which related to mechanics. These topics, together with the results for the subjective assessment of the three trial groups, are given in Table 1.

Table 1 *List of topics and results for subjective assessment*

Concepts and topics	*Index of difficulty expressed as a percentage*		
	1st year university	Post-O-grade	Pre-O-grade
(4) Difference between a vector (e.g. displacement) and a scalar (e.g. distance)	19·5	28·7	43·0
(5) Idea of uniform motion (body can maintain uniform motion without some unbalanced force to keep it moving)	26·8	30·0	57·1
(7) Idea of conservation of momentum	26·5	38·9	44·5
(8) Difference between elastic and inelastic collisions	28·9	35·1	35·6
(9) Difference between energy and power	43·2	51·6	61·3
(10) Idea of kinetic energy and potential energy	8·4	15·7	25·3

We found the results obtained for topics (9)and (10) rather puzzling. Although the results are quite self-consistent, we find it difficult to explain why the 'index of difficulty' for topic (9) is so relatively high, while that of topic (10) is so relatively low. These results conflicted with our own subjective assessment of the difficulty of these topics, based on many years' experience of teaching these topics in secondary schools. As subsequent results will show, there is no such marked difference in difficulty level when we consider the pupils' actual performance. The only explanation we can suggest runs as follows:

(i) the pupils interpret the statement 'Idea of kinetic and potential energy' at its lowest level, that is, kinetic energy is 'motion' energy and potential energy is 'stored' energy. This idea they find relatively easy to understand.

(ii) the pupils are more familiar with the 'difference between work and power' than with the 'difference between energy and power'. Since they do not relate energy to power directly, they find it relatively difficult to understand

It may be appear unusual that we are here 'inventing' plausible reasons to explain a situation in which the observed results do not agree with what we think they should show. A more 'scientific' approach would be to set up an experimental procedure to test the alternative hypothesis. We thought seriously about this, but decided not to attempt to replicate the previous study, since we accepted its findings in general terms.

We decided, however, that it would be useful to have more data to work with. We recalled that, in the Johnstone and Mughol study, the original list of topics was drawn up after consultation with a group of school and university teachers. This seemed an obvious source of expert opinion which we should not disregard. We therefore decided to involve a group of experienced teachers of physics, and others who had moved on from the classroom situation to positions as College of Education lecturers in physics, Science Advisers and members of Her Majesty's Inspectorate. Due to the geographical distribution of the latter group, we decided to use a questionnaire method to collect the data.

Before going on to describe the questionnaire, however, we must point out two other reservations we had about details of the previous investigation. The first of these relates to the multiple choice items which were used to get an objective measure of the pupils' difficulties. We did not question the basic method, but we thought the items were somewhat different, both in style and content, to the multiple choice items produced by the Scottish Certificate of Education Examination Board. We therefore had some reservations about the validity of the test items used in the previous investigation, and decided to collect more data using pretested items. (This is described in more detail in chapter 4).

We were also a little concerned about some concepts (e.g. '<u>acceleration</u>' or '<u>force</u>') which did <u>not</u> appear on the list of twenty-three concepts used in the previous study. While we realised that the original list could not be exhaustive, we felt that some important concepts had been omitted. Again the obvious answer might have been to replicate in some way the previous study with an augmented list of concepts. We decided against this as an immediate course of action because there was no guarantee that any list of concepts we might produce would necessarily be more complete than the original list. We decided to review the position after carrying out the proposed preliminary investigation.

The teacher questionnaire

As described above, it was decided to involve a group of people who were experienced at different levels in the teaching of physics. At the lower end of the experience scale we had some teachers with between two and five years' experience of presenting pupils for S.C.E. O-Grade and H-Grade Physics. At the upper end of the experience scale we had teachers with more than twenty years of practical experience. The group included fifteen practising teachers and ten others, including the Principal Examiner in Physics, the Chairman of the Scottish Central Sub-Committee in Physics, the Chairman of the Scottish Certificate of Education Physics Panel, and the author of the most widely used physics text book in Scottish schools. A majority of the total group had recent experience of marking S.C.E. examination scripts at both O-Grade and H-Grade; at least two of the group had recent experience of setting the S.C.E. H-Grade Paper II in Physics, while others regularly contributed items for the S.C.E. multiple-choice paper.

Because of the wide geographic distribution of the group, it was decided to use a questionnaire method of collecting the data. As it turned out, the design of this questionniare was not ideal and, of the original 32 questionnaires sent out, only 25 completed questionnaires were returned, though two of the original group wrote to explain why they could not complete the questionnaire. Many others annotated the questionnaire proforma with explanatory notes to indicate how they had interpreted the material. This provided very useful information which in most cases overcame the more obvious deficiences of the original questionnaire.

The questionnaire, which is reproduced in full in Appendix A, consisted of five separate parts.

In part A, the teachers were asked to write a few sentences to explain what, in their opinion, was the importance of the concepts of momentum, kinetic energy and gravitational potential energy to the study of physics at school level. They were instructed to ignore the fact that these concepts are a major feature of the S.C.E. O-Grade and H-Grade syllabuses in the hope that they would suggest reasons other than this for including these concepts.

By placing this section at the beginning of the questionnaire, we were trying to make the teachers consider such basic questions as 'Why do I teach momentum?' or 'What justification is there for including these concepts in a school physics course?' We suspected that, in most cases, the concepts are taught simply because they appear in the syllabus. Few teachers would bother to justify what they teach on any other grounds.

In part B, the teachers were asked to select, from an alphabetic listing of 50 mechanics concepts (e.g. acceleration, conservation, inelastic collision, mass, power, time, work)those which they considered were essential to a pupil's understanding of momentum, or kinetic energy or gravitational potential energy. The original 50 concepts (or more correctly 'concept labels') were taken from the published lists of specific objectives (86) for O-Grade, with a few additional H-Grade concepts added. It is expected that a pupil should 'acquire the ability to use these terms correctly in context' during his study of physics.

In part C, the teachers were asked to indicate, for each of 25 'propositions' (e.g. 'momentum is a vector quantity', 'kinetic energy is conserved in elastic collisions') at what stage of the physics course they would normally introduce the proposition. They were further asked to state the use they would make of practical experiments and/or numerical examples to develop and consolidate their pupils' understanding of the proposition. Once again, as in part B, the original source of the material used in part C is the published lists of specific objectives (86) (For reference, the specific objectives for Newtonian Mechanics are reproduced in full in Appendix B.)

In part D, the teachers were given a list of 25 suggested difficulties that pupils might experience in trying to understand these concepts. They were asked to indicate the extent of their agreement or disagreement with the given statements.

In part E, the teachers were asked to provide some statistical information about themselves, their school and their pupils.

The results of the questionnaire are given below in Tables 2-6.

TABLE 2 - Selection of comments from part A of the questionnaire

Momentum

(1) "The definition of momentum as p = mv is not particularly important in itself, but momentum does become very vital when the conservation law is developed. It is the application of this conservation law to a whole variety of situations - both theoretical e.g. in deriving the General Gas Equation and practical e.g. collisions of cars, aspects of road safety etc. - which makes the study of momentum important.
Also we would reach Newton's 2nd Law via momentum instead of via acceleration. The concept of velocity is much simpler than that of acceleration".

(2) "I cannot justify the teaching of momentum in schools"

(3) "In physics, momentum is one of the most fundamental concepts, and together with its conservation is used in studies of thermodynamics, nuclear physics, quantum mechanis and so on. Its use goes beyond physics into everyday life - in sport and safety education in particular. Commonly misused, a better

understanding should come through emphasis at school level".

(4) "(Momentum is) of fundamental importance in the development of mechanics".

(5) "(Momentum is) important through its application to conservation".

(6) "(Momentum is) important because it connected the unbalanced force and the TIME for which it is acting".

(7) "Momentum should not be introduced until 5th year at the earliest". C.S.Y.S. candidates have shown each year for the past 9 years that they confuse momentum and energy. I believe the confusion is caused by introducing momentum too soon, before the concept of energy, particularly of course KE, can be properly used by pupils. Momentum is important to physicists".

(8) "As one of the important 'invariances' in Physics, the subject would seem a little "emptier" without it".

Kinetic energy

(1) "Energy is a basic concept".

(2) "A good understanding of KE is required before you can progress to greater things in physics".

(3) "It readily identifies that a body has energy unlike a compressed spring where energy is latent. It connects the unbalanced force and the DISTANCE through which it acts".

(4) "Given the mechanical environment in which we dwell, it is natural that KE should be stressed".

(5) "Energy, strictly defined, is easier than momentum to relate to common experience. Again an essential concept, and again about motion. Again involves a conservation law."

(6) "Important in that it is probably the most easily 'grasped' form of energy, and deeper understanding of energy is brought about by its quantification.

Again it is used in a wide range of physics studies and is an essential ingredient of any physics course. More generally a better understanding of the physical environment can be achieved by simple application of the concept in a wide range of energy chains, and as such has an important part to play in general education".

(7) "As energy conservation is a useful part of physics (some would say 'central') KE must stay. $E_k = \frac{1}{2} mv^2$, however, could appear only in the H-Grade syllabus.

(8) "(Energy) should be in a school physics course - has relevance to many aspects of the environment. S3 is perhaps a bit early to introduce the **quantitative aspect - but S4 pupils can cope.** I think!!".

(Gravitational) Potential Energy

(1) Many replies were of the form 'Same comments as for K.E.'

(2) "Essential at both O and H-Grade. Again, as energy conservation is important, this must stay. Its value as E_p = mgh is also great. First, as an application of work = Fs = mgs = mgh and secondly as the simplest way of showing how energy transfer (work done) can lead to stored energy which is readily recovered".

(3) "Helpful in describing effects in other types of force fields".

(4) "The expenditure of (KE.) energy is basically against gravity or friction for most of the cases we deal with (in life and in the physics lab.) Clarifying our intuitive ideas about gravity (in energy and other terms - 'g' etc.) is an important part of the physics of our world".

(5) "This is a more difficult (concept) because of its restricted "mgh" first level treatment".

(6) "To build up concepts in 'fields', the gravitational field provides the most easily understood example. The concept has wide application in physics, engineering etc. Simple discussion can give a picture of the planetary system and 'how it works' ".

Other general comments

(1) "In all of these concepts, the general technological appreciation of society may be extended to provide a fuller knowledge of the physical world".

(2) "It is difficult to isolate these concepts. Surely their interdependence is important".

(3) "It is difficult to answer this without considering why Physics should be taught at all! I suspect that answers to your questions are bound to implicitly reflect our views on this question".

(4) "I would hope that there are still pupils in our schools who can respond to, and benefit from, the challenge presented by such topics, irrespective of their appearance in a syllabus.

(5) "They are of course important. Certainly it would be impossible to carry out an analysis of motion phenomena without expressing it in forms of some of these ideas. The problem to my mind is in convincing the pupils that these concepts are important".

TABLE 3

Results for Part B of the questionnaire

LIST OF CONCEPTS	MOMENTUM			KINETIC ENERGY			GRAVITATIONAL POTENTIAL ENERGY		
	ESSENTIAL	DESIRABLE	IRRELEVANT	ESSENTIAL	DESIRABLE	IRRELEVANT	ESSENTIAL	DESIRABLE	IRRELEVANT
1. Acceleration	2	15	5	6	15	2	14	9	0
2. Action (force)	15	7	1	9	4	10	14	2	7
3. Addition of vectors	18	5	1	2	0	21	2	4	17
4. Average acceleration	0	6	16	1	8	14	2	7	14
5. Average speed	5	11	7	7	9	6	3	6	15
6. Component (of a force)	4	4	14	4	4	15	6	9	9
7. Conservation	21	4	0	19	6	0	14	6	3
8. Direct collision	19	5	0	5	8	9	3	2	16
9. Displacement	12	7	4	6	9	8	15	5	4
10. Distance	13	6	2	14	7	2	19	2	2
11. Efficiency	0	0	25	0	4	19	0	3	20
12. Elastic collision	20	4	1	7	11	5	2	4	18
13. Energy	4	10	8	21	2	0	22	1	0
14. Energy input	3	4	16	8	10	6	10	8	5
15. Energy output	3	4	16	8	10	6	10	8	5
16. External force (on a system)	13	7	3	10	7	6	11	8	3
17. Force	19	5	0	14	9	0	22	2	0
18. Frequency	2	3	18	1	2	20	0	1	22
19. Gravitational field strength	0	0	23	1	9	13	20	5	0
20. Gravity	0	0	23	1	15	7	25	0	0
21. Impulse	11	9	4	2	5	15	0	2	21
22. Inelastic collision	19	4	1	11	9	4	2	2	18
23. Inertia	11	8	2	6	12	4	4	11	8
24. Interaction(of bodies)	19	5	0	6	11	5	4	9	8
25. Interconversion (of energy)	5	10	8	22	3	0	21	3	1

TABLE 3 continued.

	MOMENTUM			KINETIC ENERGY			GRAVITATIONAL POTENTIAL ENERGY		
LIST OF CONCEPTS	ESSENTIAL	DESIRABLE	IRRELEVANT	ESSENTIAL	DESIRABLE	IRRELEVANT	ESSENTIAL	DESIRABLE	IRRELEVANT
26. Joule	3	8	12	20	4	1	17	5	1
27. Kinetic energy	2	11	9	25	0	0	6	10	6
28. Machine	0	0	22	2	8	13	2	7	14
29. Mass	25	0	0	23	2	0	25	0	0
30. Momentum	25	0	0	2	10	11	1	6	16
31. Newton	7	11	5	13	8	2	18	6	0
32. Newton-second	9	10	5	0	7	16	0	2	21
33. Oblique collision	13	7	5	3	8	11	0	1	22
34. Potential energy	2	6	15	10	12	1	24	1	0
35. Power	0	2	21	3	9	12	0	9	14
36. Reaction (force)	16	5	3	3	4	16	7	4	12
37. Resolution (of vectors)	12	3	9	3	2	18	3	7	14
38. Resultant	12	6	4	3	4	16	3	9	12
39. Scalar	13	7	2	11	8	5	11	9	4
40. Speed	23	1	0	19	4	1	6	11	7
41. System	13	6	4	9	4	7	10	4	9
42. Time	21	0	3	18	2	2	10	4	9
43. Unbalanced force	10	11	1	10	8	5	14	5	5
44. Uniform speed	18	2	2	17	4	1	9	6	8
45. Uniform velocity	18	3	2	13	6	4	9	6	8
46. Vector	22	3	0	10	7	6	13	5	6
47. Velocity	23	2	0	18	4	3	10	6	9
48. Watt	0	1	22	2	10	11	3	7	12
49. Weight	2	6	15	3	10	9	25	0	0
50. Work	1	6	16	17	7	1	23	2	0

TABLE 4 - Key concepts, in order of popularity

MOMENTUM	KINETIC ENERGY	GRAVITATIONAL POTENTIAL ENERGY
1. Mass	1. Kinetic energy	1. Gravity
2. Momentum	2. Mass	2. Mass
3. Velocity	3. Interconversion (of energy)	3. Weight
4. Speed	4. Conservation	4. Potential energy
5. Vector	5. Energy	5. Work
6. Conservation	6. Joule	6. Force
7. Elastic collision	7. Speed	7. Interconversion (of energy)
8. Direct collision	8. Velocity	8. Energy
9. Force	9. Work	9. Gravitational field strength
10. Interaction	10. Time	10. Newton
11. Inelastic collision	11. Uniform speed	11. Distance
12. Time	12. Force	12. Joule
13. Addition of vectors	13. Distance	13. Acceleration
14. Uniform velocity	14. Newton	14. Displacement
15. Uniform speed	15. Potential energy	15. Conservation
16. Action (force)	16. Uniform velocity	16. Unbalanced force
17. Reaction (force)	17. Inelastic collision	17. Scalar
18. Scalar	18. Scalar	18. Vector
19. External force (on a system)	19. Unbalanced force	19. Action (force)
20. Oblique collision	20. Acceleration	20. External force
21. Distance	21. Vector	
22. System	22. External force	
23. Displacement		
24. Unbalanced force		
25. Impulse		
26. Inertia		
27. Resultant force		

TABLE 5 - Results for Part C of the questionnaire

LIST OF PROPOSITIONS	ESSENTIAL?			YEAR TAUGHT?				PUPIL EXPERIMENT	DEMON. EXPERIMENT	NUMERICAL CALC.	NO RESPONSE
	YES	NO	OMIT	2	3	4	5				
1. Physical quantities can be classfied as vectors or scalars	23	1	1	-	21	8	4	9	4	15	10
2. A vector quantity is only specified it its direction as well as its magnitute is known	23	1	1	-	21	8	5	8	5	16	8
3. The momentum of an object is the product of its mass and velocity	24	0	1	-	14	15	5	19	15	21	3
4. Momentum is a vector quantity	23	1	1	-	13	15	7	14	8	19	6
5. The product of a force and the distance moved along its line of action is a measure of the work done and of the energy transferred	23	1	1	-	17	10	3	12	10	20	4
6. Energy is a scalar quantity	23	1	1	-	18	9	5	3	2	13	12
7. Energy is measured in joules	24	0	1	1	20	8	3	5	3	20	4
8. Power is the rate at which energy is transferred	22	0	3	-	19	9	4	5	2	15	9
9. Power is measured in watts	22	0	3	-	20	9	3	8	4	21	4
10. The kinetic energy of a mass m moving at a speed v is given by $E_k = \frac{1}{2} mv^2$	24	0	1	-	15	12	6	12	13	21	4

TABLE 5 - continued.

LIST OF PROPOSITIONS

	ESSENTIAL?			YEAR TAUGHT?				PUPIL EXPERIMENT	DEMON. EXPERIMENT	NUMERICAL CALC.	NO RESPONSE
	YES	NO	OMIT	2	3	4	5				
11. The change in potential energy of a mass m moved a vertical distance h in a gravitational field is given by $E_p = mgh$	24	0	1	1	18	10	3	10	6	21	3
12. In a system on which there are no external forces acting, kinetic energy may be converted without loss into potential energy and vice versa	19	0	6	1	13	12	8	5	8	16	7
13. The impulse of a force is the product of the force and the time for which it acts	19	3	3	-	4	1	16	7	9	16	8
14. Impulse is measured in newton-seconds	19	3	3	-	4	1	16	0	1	15	10
15. The impulse of a force is measured by the change in momentum it produces in an object	19	3	3	-	4	1	16	7	11	16	8
16. Momentum is measured in newton-seconds	15	6	4	-	3	3	14	2	1	14	11
17. The rate of change of momentum of an object is a measure of the unbalanced force applied to the object	19	0	6	-	4	4	12	5	4	16	8

TABLE 5 continued

LIST OF PROPOSITIONS	ESSENTIAL?			YEAR TAUGHT?				PUPIL EXPERIMENT	DEMON. EXPERIMENT	NUMERICAL CALC.	NO RESPONSE
	YES	NO	OMIT	2	3	4	5				
18. Action and reaction forces are equal in magnitude but opposite in direction	23	0	2	1	14	10	5	10	12	17	6
19. The efficiency of a machine is the ratio of the useful energy output to the energy input	21	1	3	-	17	11	3	20	8	20	5
20. Collisions may be classified as elastic or inelastic	23	1	1	-	12	12	5	16	10	14	8
21. Kinetic energy is conserved in elastic conditions	23	0	2	-	12	13	4	15	8	20	5
22. In inelastic collisions, kinetic energy is converted into some other form of energy	23	0	2	-	12	13	4	14	7	16	7
23. For the special case of collisions in one dimension, momentum is conserved in a system that has no external force acting on it	22	0	3	-	13	13	5	21	11	19	3

TABLE 5 continued

LIST OF PROPOSITIONS	ESSENTIAL?			YEAR TAUGHT?				PUPIL EXPERIMENT	DEMON. EXPERIMENT	NUMERICAL CALC.	NO RESPONSE
	YES	NO	OMIT	2	3	4	5				
24. In a system that has no external force acting on it, momentum is conserved in two dimensions	22	1	2	-	-	1	19	10	9	17	7
25. In a system on which an external force is acting, the work done by the force is a measure of the kinetic and/or potential energy transferred	20	2	3	-	7	13	10	3	8	18	7

TABLE 6

Results for Part D of the questionnaire

	STRONGLY AGREE	AGREE	DISAGREE	STRONGLY DISAGREE	NO ANSWER
1. Pupils have difficulty in distinguishing between scalars and vectors	2	10	8	2	3
2. Pupils find the idea of conservation of momentum difficult	2	12	8	0	3
3. Pupils cannot distinguish between elastic collisions and inelastic collisions	1	8	11	2	3
4. Pupils confuse energy with power	5	10	7	0	3
5. In numerical calculations, pupils treat momentum as a scalar quantity	4	13	5	0	3
6. In numerical problems involving collisions, pupils treat all collisions as one-dimensional	5	11	6	0	3
7. In numerical calculations, pupils apply formulae blindly	3	14	3	1	4
8. Pupils do not get sufficient practice in solving numerical problems	8	8	5	1	3
9. Pupils do not have the necessary mathematical skills to solve numerical problems	8	8	6	0	3
10. To many pupils, energy is just a name	2	14	6	0	3
11. The concept of momentum should be introduced in S3	1	8	8	3	5
12. The concept of energy should not be introduced until S3	0	0	16	5	4
13. The concept of conservation should be introduced in S1	5	9	3	3	5
14. Pupils should be given more 'concrete' experience of momentum in S1 and S2	0	4	12	5	4
15. Pupils should be given more 'concrete' experience of energy in S1 and S2	1	11	9	0	4

TABLE 6 continued

	STRONGLY AGREE	AGREE	DISAGREE	STRONGLY DISAGREE	NO ANSWER
16. Pupils can only develop the concepts of momentum and energy by doing practical experiments	6	12	3	1	3
17. Teacher demonstrations are of little value in developing the pupils' understanding of such concepts	2	1	15	4	3
18. Pupils think they understand the concepts of momentum and energy	0	11	9	0	5
19. The concepts of momentum and energy are just too difficult for the average O-Grade pupil	1	0	18	3	3
20. Momentum experiments with trolleys and friction-compensated runways are completely divorced from reality	1	7	12	1	4
21. Pupils cannot transfer their knowledge of collisions between trolleys to 'real-life' situations	1	8	12	1	3
22. Teachers expect too much of pupils	2	7	11	0	5
23. Pupils have difficulty in understanding why, in any collision, momentum <u>must</u> be conserved, but kinetic energy <u>may</u> be conserved	5	11	5	1	3
24. Pupils confuse momentum with inertia	0	3	12	4	6
25. The difficulties pupils have in understanding the concepts of momentum and energy are largely due to poor teaching	2	7	9	3	4

Discussion of results

Results from part A of the questionnaire indicate that

(i) all teachers think that the study of energy is essential and must be included in any physics course.

(ii) most teachers would also include momentum but appreciate that it is not essential up to O-Grade. It is important to future physicists

(iii) the inclusion of momentum conservation and a quantitative treatment of energy are considered to be essential for subsequent theoretical studies in physics e.g. thermodynamics, nuclear physics, quantum mechanics.

(iv) the study of energy and momentum are also considered to be valuable in a practical way in "providing a fuller knowledge of the physical world". As such they should be included in a school physics course.

In part B, it was reported that some of the given concepts could not be classified as 'essential', 'desirable' or 'irrelevant' unless one was also informed of

(i) what level of complexity of the concept was involved,
(ii) what prior knowledge was expected of the pupil,
(iii) what experimental methods were likely to have been used in teaching the concept.

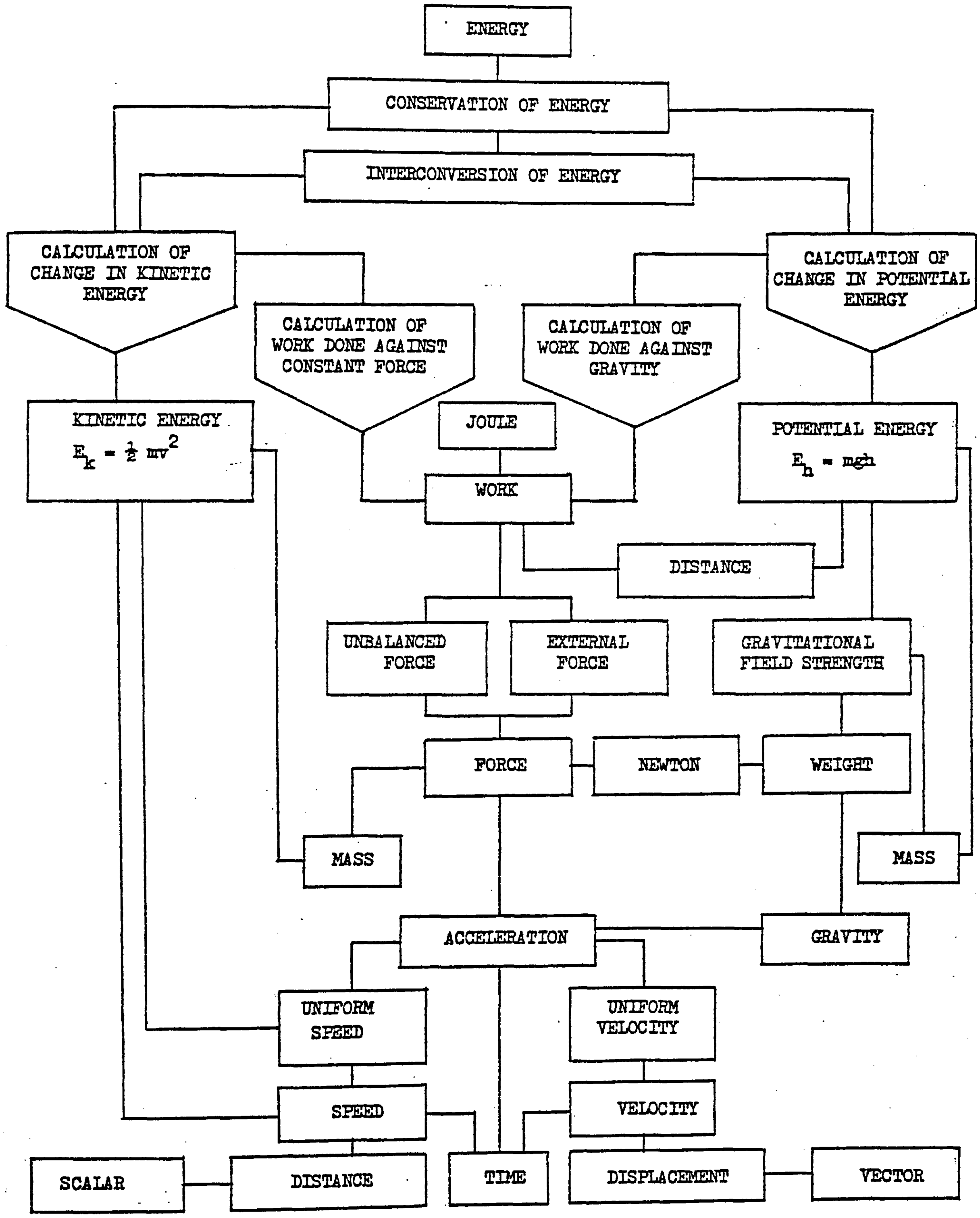
The study of 'momentum', for example, involves both conservation of momentum and change of momentum. The essential concepts for momentum conservation are not the essential concepts for momentum change. Or again, the concept of 'kinetic energy' might mean 'motion' energy to an S3 pupil, '$E_k = \frac{1}{2} mv^2$' to an S4 pupil and 'temperature $= \frac{1}{2} mc^2$' to an S5 pupil. The instructions given about how the questionnaire was to be completed did not stipulate clearly that, in Part B, we were referring to the level of understanding of the concepts of an H-Grade pupil.

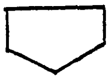
In spite of such difficulties, there was a marked degree of agreement in opinion as to which were the essential sub-concepts contributing to the pupil's understanding of the concepts of momentum and energy. These essential or key concepts are listed, in order of popularity, in Table 4. It will be noted that the concept of 'power' does not appear in any list.

Concept diagrams were prepared, based on the consensus opinion of what were the key concepts, to show how the various sub-concepts were inter-related and where there was a hierarchical structure of sub-concepts.

Figure 2 shows such a concept map for 'energy'.

Figure 2 - Concept mapping for 'energy' based on the consensus opinion of the teacher questionnaire.



[The statements in  boxes did not appear in the original list of concepts given to the teachers.]

This indicates that conservation of energy subsumes inter-conversion of energy, which in turn forms the apex of two inter-related hierarchical chains, one for kinetic energy and one for potential energy. (For clarity, only the most obvious inter-relationships are shown. The statements in  boxes did not appear in the original list of concepts).

Although the casual observer may be duly impressed by the symmetrical arrangement of the concepts in *Figure 2*, it should be noted that this pattern only emerged after much careful thought. It is not suggested, of course, that the format of *Figure 2* is more 'valid' than other possible formats, though it is possibly the most compact format. It highlights certain important features:-

(i) the concept of '*work*' is no less important than '*kinetic energy*' or '*potential energy*'

(ii) The concept of '*force*' is a prerequisite concept (a subsumer) of '*work*', just as '*weight*' is probably a subsumer of '*potential energy*'

(iii) It is difficult to see exactly where the concept of '*power*' might be fitted into the chart, except, perhaps, by using a cyclic rather than a linear format with '*power*' linking '*energy*' at one end of the concept map to '*time*' at the other end.

(iv) The obvious complexity of the concept 'map' would make an empirical validation of it, as a 'learning hierarchy', very difficult.

If we reconsider Johnstone and Mughol's work, in the light of our concept mapping, it would appear that:-

(i) the suggested difficulty in understanding the 'difference between energy and power' may have been exaggerated

(ii) the concept of 'force' (and 'weight') should be included in any future study of mechanics concepts.

In <u>part C</u>, most of the teachers agreed that the propositions in the given list were essential, though some preferred the term 'desirable' since not all the listed propositions would be required. In particular, the propositions involving 'impulse' were considered unnecessary for O-Grade. Several teachers pointed out that they did not explicitly teach such propositions. The Principal Examiner in Physics pointed out that, to his knowledge, no S.C.E. physics examination had specifically required the <u>recall</u> of any of the listed propositions. This was agreed and it is accepted that pupils can often solve a 'concrete' mathematical problem yet be unable to formally state the underlying proposition. An intuitive grasp of the idea coupled with the rote learning of a formula may be all that is required. Of the given list of propositions, most of them were introduced in S3, with a few more in S4. Propositions involving impulse and two-dimensional collisions were not introduced until S5. To help the pupils' understanding of the propositions, typical numerical examples were invariably done and, in many cases, suitable practical experiments were performed.

The results from <u>part D</u> were inconclusive in that none of the given statements achieved complete agreement or disagreement.

The statements which achieved most general agreement were:

(1) "Pupils can develop the concepts of momentum and energy only by doing practical experiments"

(2) "Pupils do not have the necessary mathematical skills to solve numerical problems"

(3) "Pupils do not get sufficient practice in solving numerical problems"

The statements which achieved most general disagreement were -

(1) "The concept of energy should not be introduced until S3"

(2) "The concepts of energy and momentum are just too difficult for the average O-Grade pupil"

(3) "Teacher demonstrations are of little value in developing the pupils' understanding of such concepts".

It may be of interest to note that the first four statements on the list were simply rewordings of the pupil difficulties highlighted by the previous research study. Our results did not indicate that the teachers saw these as problem areas for their pupils. For example, nine teachers agreed that "pupils cannot distinguish between elastic collisions and inelastic collisions", but thirteen disagreed with this statement. Twelve teachers agreed that "pupils have difficulty in distinguishing between scalars and vectors" but ten disagreed with this.

The results from <u>part E</u> of the questionnaire confirmed that no teacher in the group had less than two years' experience of presenting pupils for S.C.E. O-Grade and H-Grade examinations. More than 60% of the practising teachers had more than 5 years presentation experience. The majority of the teachers taught in large, well equipped comprehensive schools and a basic textbook, supplemented by the teacher's own notes, was used in almost all cases.

Conclusion

The teacher questionnaire revealed the following

(1) Teachers consider the concepts of momentum and energy to be important and worthy of inclusion in any school physics course.

(2) Teachers can identify by consensus opinion the important prerequisite concepts for each of the given concepts. There is little dispute as to the essential sub-concepts, but a greater variety of opinion as to what are desirable sub-concepts.

(3) Teachers agree that pupils should acquire a body of knowledge (which can conveniently be stated as a series of propositions) but they do not think the pupils should be required to apply the knowledge explicitly in the form of propositions. There is a marked reaction against the suggestion that the critical attributes of concepts should be presented to pupils as a matter of definition.

(4) Teachers see a value in practical work in assisting the pupils to form the desired concepts. They make extensive use of numerical examples to consolidate the pupils' understanding of the desired concepts, but accept that not all pupils are proficient in the necessary mathematical skills.

(5) Teachers are aware that their pupils have difficulty in understanding the concepts of momentum and energy, particularly in progressing beyond a simple intuitive grasp of the concepts, but they do not attribute this to any subject specific difficulty or to poor teaching. The reasons for the pupils' perceived difficulties must be attributed to the pupils themselves.

We found this last point rather surprising at first. It appeared that the teachers were tacitly accepting that some pupils were having difficulty in understanding these concepts, without considering how the situation might be improved if alternative teaching strategies were adopted. Brown (85) has noted the same reaction "In providing the means of attributing lack of universal success among pupils to the 'natural' characteristics of these pupils, the idea (of general ability) has deterred teachers from examining the instructional conditions they provide from the perspective that it is these conditions that determine what pupils learn."

Our own experience of teaching physics in both selective and comprehensive schools and, latterly, of training teachers of physics, has led us to believe that there is a direct relationship between pupil attainment and teacher expectation and that teachers generally underestimate rather than over-estimate their pupils' capabilities.

The teachers are not likely to alter their preconceived ideas about their pupils' abilities unless they have some direct evidence of what the pupils can and cannot do. This suggests that there may be a place for some form of systematic diagnostic assessment of pupils' abilities. We will take up this suggestion again in a later chapter.

The questionnaires were completed in 1977. Some four years later, we used a very similar group of physics teachers to validate some test material. (This will be described in full in a later chapter). We decided to ask again if the teachers "could identify any factors which might explain their pupils' reported difficulties." This time we let the teachers suggest the likely areas of difficulty. The results were much more conclusive on this occasion.

14 out of 17 mentioned the vector nature of momentum, 11 mentioned loss in E_k in collisions or doing work against external force, 12 mentioned applying Newton's laws either for resultant force or in action/reaction situations, and 14 mentioned the use of 'impulse' in problem solving, as being likely areas of difficulty for an H-Grade pupil.

Clearly the teachers are aware of likely areas of difficulty. The fact that this information did not emerge from the original questionnaire must be attributed to the poor design of the questionnaire.

CHAPTER 4 - THE PUPIL TESTS

Introduction

In this chapter, we will describe the second stage of our preliminary investigation of the area of mechanics. We noted in the last chapter that we had some reservation about the multiple-choice items used in the Johnstone and Mughol study. In our opinion, these items were sufficiently different in format, language and style from the type of multiple-choice item set by the Scottish Certificate of Education Examination Board to make us doubt the validity of many of the items used in the previous study. We decided, therefore, to conduct further tests, specifically in the area of mechanics, but using what we considered to be more valid multiple-choice items. We hope, by so doing, to identify at least some of the pupils' difficulties in the area of mechanics.

Existing methods of assessing 'cognitive ability' in physics.

The Scottish Certificate of Education Examination Board use two distinct methods of assessing what they describe as 'essentially cognitive abilities'. At both O-Grade and H-Grade the terminal examination consists of two separate papers.

The O-Grade examination consists of Paper I of $1\frac{1}{2}$ hours duration and Paper II of 1 hour's duration. Paper I is an extended answer paper containing eight equally weighted questions from which the candidate is required to attempt five. Paper II is a multiple choice paper containing forty pre-tested items each containing five possible responses, only one of which is to be selected.

The H-Grade examination consists of Paper I of $1\frac{1}{2}$ hours duration and Paper II of $2\frac{1}{2}$ hours duration. Paper I contains forty pre-tested, multiple-choice items each containing five responses. Paper II contains ten equally weighted questions from which the candidates is required to attempt eight.

The multiple-choice papers are constructed to provide a balance in terms of syllabus coverage and also in terms of four ability categories, Knowledge, Comprehension, Application and Highest Abilities. These ability categories are based on Bloom's (87) taxonomy, and are explained in more detail in Appendix C. We can illustrate their use by reference to actual test items.

Category A - Knowledge

"The kinetic energy of a particle of mass m travelling at speed v is given by

A. $\frac{1}{2}mv$ B. mv^2 C. $\frac{1}{2}m^2v$ D. m^2v^2 E. $\frac{1}{2}mv^2$ "

(Here the pupil is required to recall a specific 'bit' of information)

Category B - Comprehension

"The kinetic energy of a bullet fired with velocity v is 2J. What is the kinetic energy of the same bullet fired with velocity 4v ?

A. 4J B. 8J C. 16J D. 32J E. 64J "

(Here the pupil is required to apply a specific principle to a situation where it should be obvious to the pupil which principle should be used)

Category D - Highest abilities

"Two moving bodies, P and Q, have the same momentum but the kinetic energy of P is twice the kinetic energy of Q. The mass of P is

A one quarter the mass of Q
B one half the mass of Q
C the same as the mass of Q
D twice the mass of Q
E four times the mass of Q

(Here the pupil is required first to select and then apply the appropriate principles to a problem situation, the solution to which involves two or more stages)

In practice, it is often difficult to make a clear distinction between comprehension (applying a principle in a familiar situation) and application (applying a principle in an unfamiliar situation) since the degree of familiarity with the situation will depend upon what the pupil has been taught. An item may have to be categorised as 'comprehension/application' to get round this difficulty.

The extended answer papers are constructed to provide a balance in terms of coverage of both syllabus content and four ability groupings, Communication, Systematic Problem Solving, Data Analysis and Creativity. These four ability groupings are explained in detail in Appendix D, but we can illustrate their application by reference to two actual questions.

1980 H-Grade Paper II Q.1.

Marks

1. (*a*) A balloonist suspects he is losing height. In order to assess his rate of fall, he reads an instrument which measures, to the nearest metre, height above ground level. Readings are taken at 20 second intervals. These are shown in Table A.

TABLE A

Time (s)	0	20	40	60
Height (m)	1000	985	960	925

(i) Use these values to calculate the vertical component of the acceleration of the balloon.

(ii) The total mass of the balloon and contents is 500 kg. Calculate the resultant force acting vertically downwards on the balloon during this observation period. **4**

(*b*) To reduce his downward acceleration, the balloonist empties some sand overboard. After doing this he continues taking readings. These are shown in Table B.

TABLE B

Time (s)	80	100	120	140
Height (m)	885	845	805	765

(i) What is the **resultant** vertical force now? Give your reasoning.

(ii) Draw a diagram showing the individual vertical forces acting on the balloon system during this second observation period. Name each force.

(iii) Calculate the mass of sand which was emptied overboard. **6**

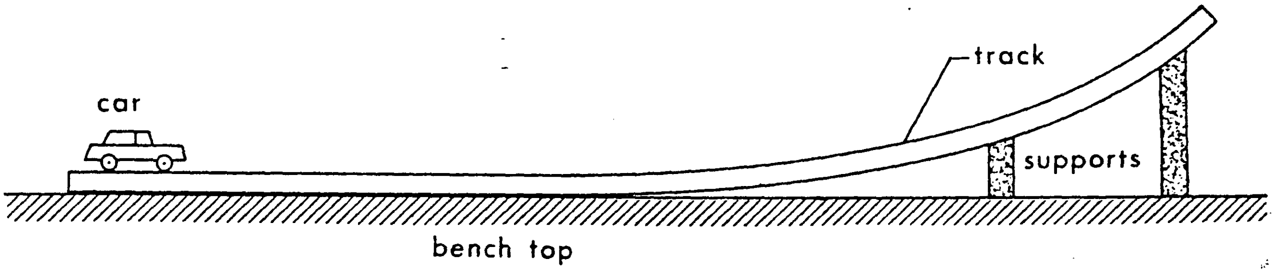
(10)

In the above question, part b(ii) involved communication, parts a(ii), b(i) and b(iii) involved systematic problem solving and part a(i) involved data analysis.

1981 H-Grade Paper II. Q.3.

Marks

3. Two pupils are asked to measure the speed of a pellet fired from an air rifle. They are supplied with a model car and a plastic track set up as shown in the sketch.



They are also given an air rifle, a box of pellets, a lump of plasticine, a metre stick and a balance for weighing.

(a) Describe how the pupils can find the speed of the pellet using only the apparatus mentioned above.

In your description state:

(i) how the pupils carry out the experiment;

(ii) what measurements they make;

(iii) how the application of the principle of conservation of momentum and the consideration of the interchange of energy enable them to calculate the speed of the pellet from these measurements. **8**

(b) Give one major source of error in this experiment and explain whether it produces an underestimate or overestimate for the speed of the pellet. **2**

(10)

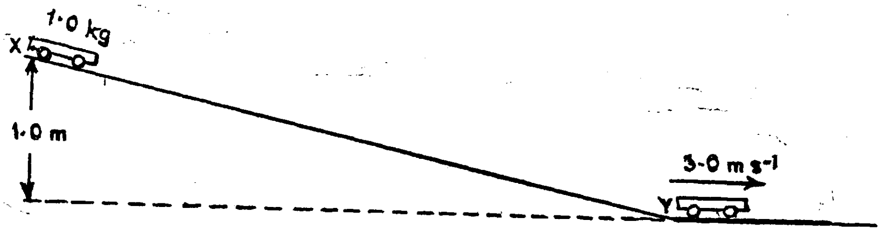
In this question, all of part (a) involved creativity, while part (b) involved communication.

(In and after 1982, it is proposed to change the format of the H-Grade examination, but this will not affect the present investigation).

The questions set in the O-Grade and H-Grade examinations have had, and will no doubt continue to have, a marked 'feedback' effect on the teaching of physics in schools. They provide the official interpretation of syllabus content in terms of depth of treatment required, question style, language and relative emphasis on different syllabus areas. Teachers, being aware of this, pay particular attention to the questions set in these examinations, and quickly incorporate any new style of question or change of emphasis in a particular area of the syllabus into their teaching routine. In a very real sense, therefore, the level of conceptual understanding required of the pupils is more explicitly 'spelt out' in the O-Grade and H-Grade examinations than in the published syllabus.

Teachers make extensive use of questions from previous O-Grade and H-Grade examinations, supplemented by similar questions from other sources (88), to assess pupil attainment. The multiple-choice items are frequently used as revision tests within the classroom, while the extended answer questions are more often given as homework or used in term examinations. In a way this is understandable since these questions indicate the standard against which their pupils will ultimately be measured and, as long as their pupils can successfully answer such questions, the teachers can assume they have attained the desired level of understanding. The problem arises when the pupils cannot answer a question or selects the wrong response to a multiple choice item. Does this mean the pupil has failed to reach the desired level of conceptual understanding and, if so, can the teacher identify where the failure has occurred?

To take a particular example, suppose a pupil chooses answer B in the following multiple choice item, what does this really mean?

> A trolley of mass 1.0 kg is released from rest as shown from the top of a slope. When it reaches the bottom of the slope it is travelling at 3.0 ms^{-1}.
>
> 
>
>
> The work done against friction while moving from X to Y must have been
>
> A 1.0 J
> B 4.5 J
> C 5.5 J
> D 9.0 J
> E 10.0 J (<u>1975 H-Grade Physics, Paper I, Q.13</u>)

Since the correct answer is C, we might simply say the pupil 'got it wrong'. However a closer examination would reveal that the pupil has correctly worked out the value of E_k at the bottom of the slope, but has not subtracted this from the original E_p of 10.0 J to find the loss in E_k in moving down the slope. He has appreciated that the solution to the problem requires the calculation of E_k. Is he therefore more knowledgeable than another pupil who thinks the answer is E ? And how does this pupil, in turn, compare with one who arrives at the answer A by using the formula $E_k = mv^2$ instead of $E_k = \frac{1}{2} mv^2$?

When we start to consider what can be inferred from the pupil's wrong answer to a multiple choice item, we soon realise that we can get little reliable information about what the pupil does not know from a single wrong response. (It is equally true that we get little reliable information about what he does know from a single correct response). We need to examine the pattern of responses to a number of items before we can hope to identify what is it that the pupil does not know, or for that matter what it is that the pupil knows.

The problem can be compared to concept formation. No concept is formed by a single instance. A concept is the pattern of common features from a wide variety of separate instances. The more varied the separate instances, the more meaningful the concept becomes. In the same way, a single item tells us little about the pupil's understanding, but the cumulative evidence provided by a comprehensive battery of items can tell us a great deal.

The problem of trying to infer, from the pupil's wrong answer, how much the pupil actually knows, is more noticeable, perhaps, in multiple-choice items which involve more than one stage of reasoning (as in the example quoted above) but similar problems will arise with extended-answer questions. In the marking of such questions, it is not uncommon, for example, to find that a prepared marking scheme has to be extended to accommodate the unanticipated, partially correct answer. To decide how much credit such 'wrong' answers should be given requires that we infer a level of understanding from the answer given.

If we hope to be able to make any valid conclusions about the pupil's level of understanding from the results of a multiple-choice test then:

(i) We need a reasonable number of items in the test to give an adequate sampling of ability.

(ii) we need to know what each item, or group of items, is intended to test i.e. the test must have content validity in terms of agreed objectives.

(iii) we need a method of analysing the results of the test which will reveal response patterns for both correct and incorrect responses.

(iv) we need to be able to interpret the test scores in a meaningful way i.e. the test must have construct validity.

The compilation of the multiple-choice tests

We decided to compile two separate tests, one on the concept of 'momentum',the other on the concept of 'energy' .

To ensure that the material included in the two tests was appropriate, the published specific objectives for the O-Grade physics course (86) dealing with momentum and energy were used as a guide when selecting test items. The specific objectives for Newtonian Mechanics are reproduced in full in Appendix B, but, for convenience we list, in Table 7, the ones we used in making up the tests. Additional specific objectives were prepared for H-Grade. These are given in Table 8.

Table 7. Specific objectives on momentum and energy for O-Grade Physics.

Pupils should acquire the ability to:

O.1 recall that the momentum of an object is the product of its mass and velocity

O.2 recall that momentum is a vector quantity

O.3 recall that the product of a force and the distance moved along its line of action is a measure of the work done and of the energy transferred

0.4 recall that energy is a scalar quantity

0.5 recall that power is the rate at which energy is transferred

0.6 recall that, for the special case of interactions in one dimension, momentum is conserved in a system that has no external forces acting on it

0.7 recall that action and re-action forces are equal in magnitude but opposite in direction

0.8 relate action and re-action pairs of forces to the objects on which each force acts

0.9 calculate the kinetic energy of a moving object given its mass and speed

0.10 calculate the change in potential energy of a mass moved in a gravitational field

0.11 apply the Law of Conservation of Momentum to the solution of simple one-dimensional interaction problems

0.12 solve simple problems on the interconversion of kinetic and potential energy

0.13 solve simple numerical problems involving energy transfer, work and power

0.14 interpret some simple physical phenomena in terms of momentum conservation

0.15 compare elastic and inelastic collisions in terms of kinetic energy conservation

0.16 use the following terms correctly in context: energy, potential energy, kinetic energy, action, re-action, momentum, conservation, elastic collision, inelastic collision, work, power, joule, watt.

Table 8. Additional specific objectives on momentum and energy for H-Grade Physics

Pupils should acquire the ability to :

H.1 recall that the impulse of a force is the product of the force and the time for which it acts

H.2 recall that the impulse of a force is measured by the change in momentum it produces in an object

H.3 relate the average value of an applied force to the time for which the force acts and the change in momentum it produces

H.4 apply the Law of Conservation of Momentum to the solution of simple two-dimensional interaction problems

H.5 solve simple numerical problems involving the interconversion of kinetic and potential energy in non-conservative systems

H.6 interpret some simple physical phenomena in terms of momentum conservation in more than one dimension

H.7 interpret force-time graphs both qualitatively and quantitatively

H.8 interpret velocity-time graphs involving collisions

H.9 relate energy-time graphs to the corresponding velocity-time graphs

We considered that the validity and the reliability of the tests would be enhanced by using pretested, published items in preference to producing completely original (and therefore untested) items. Appropriate test items from the S.C.E. O-Grade and H-Grade examinations were thus included in both the momentum and the energy tests. Since only a few suitable test items were available from this source, the majority of the items used in the tests were selected from an alternative source (88) of equivalent standard. While the use of published test items must increase the likelihood that a number of the items used in the tests had been seen by pupils on some previous occasion, any beneficial effect this may have had on the pupils' performance has been assumed to be negligible.

Each test consisted of 40 items, each item having five responses. Each item was selected to test one or more of the specific objectives listed in the tables given above. Although these objectives do not appear to be in a hierarchical order, an objective appearing towards the end of the list will often include one or more of the earlier objectives on the list. For example, objective 11 in Table 7 states that the pupil should acquire the ability to "apply the law of conservation of momentum to the solution of simple one dimensional problems." To demonstrate that he has attained this objective, the pupil must also demonstrate that he has acquired the ability to "recall that, for the special case of interaction in one dimension, momentum is conserved in a system that has no external force acting on it" (objective 6); "recall that momentum is a vector quantity" (objective 2) and "recall that the momentum of an object is the product of its mass and velocity" (objective 1)

In the same way, to be able to "solve problems on the interconversion of kinetic and potential energy" (objective 12), the pupil is likely to have to "calculate the kinetic energy of a moving object given its mass and speed" (objective 9), and to "calculate the change in potential energy of a mass moved in a gravitational field" (objective 10) and, perhaps, to "recall that energy is a scalar quantity" (objective 4)

Thus any one test item may, of necessity, be testing more than one specific objective. For simplicity, however, each item has been shown, in Table 9, against the highest order objective to which it applies.

Table 9 - Momentum and energy test items related to specific objectives

Objective	Momentum Test Items	Energy Test Items
0.1	1, 2, 3, 4, 11, 21, 31	13, 18, 22, 33, 38
0.2	13, 16, 27	7
0.3		3, 5, 9, 11, 12, 14, 40
0.4	16	1, 16
0.5		30, 31
0.6	5, 6, 7	
0.7	17	
0.8	18. 25	
0.9	11, 16, 21, 31	2, 6, 7, 8, 13, 18, 22, 33, 38
0.10		10, 15
0.11	8, 9, 14, 15, 30	26, 27, 29
0.12		17, 19, 20, 21, 23, 24
0.13		32
0.14		
0.15	26	26, 27, 28, 29
0.16		4
H.1		
H.2	12, 19	
H.3	20, 23, 24, 29, 32, 34, 35	
H.4	36, 38	
H.5		25, 36
H.6	37, 39	
H.7	22, 33	
H.8	10, 28, 40	39
H.9		34, 35, 37

When selecting items for the tests, care was taken to include items which would test the topics which previous research had highlighted as problem areas. Table 10 shows the mean facility value of the items from the two tests which were considered to be testing these topics.

Table 10 - Areas of difficulty from previous research

	Mean facility value		
	S4	S5	S6
Difference between a vector and a scalar	0.41	0.57	0.59
Idea of conservation of momentum	0.43	0.54	0.58
Difference between elastic and inelastic collisions	0.47	0.57	0.68
Idea of kinetic and potential energy	0.50	0.61	0.63
Difference between energy and power	0.44	0.56	0.59

The results show that, in every case, the performance of pupils in S5 and S6 (i.e. H-Grade) is significantly better ($t \geqslant 2.69$ or $p < 0.01$) than the performance of pupils in S4 (i.e. O-Grade).

While these results are in general agreement with the results obtained from the previous research study, there is one important difference. For each group of pupils, there is no significant difference in mean facility values for the different topics. In particular, the pupils found 'the idea of kinetic and potential energy' was not significantly easier than 'the difference between energy and power'.

Each test item was given an appropriate ability category grading (A, B, C or D) according to whether it involved knowledge, comprehension, application or some higher ability. A given specific objective was generally tested at more than one level.

Table 11 shows the distribution of ability categories for the items in each test. It will be noted that the two distributions are very similar, so the tests should be of approximately equal difficulty. This was later confirmed by the best results, which showed the same median mark for each test.

Table 11 - Distribution of categories for the items in each test.

	Momentum test				Energy test			
Category	A	B	C	D	A	B	C	D
Number of items	4	17	10	9	4	15	11	10

The momentum test is reproduced in full in Appendix E while the energy test is to be found in Appendix F. In each case we have photo-reduced the original typescript by 20%.

Administration of the Tests

The tests were administered to some 300 S.C.E. O-Grade and H-Grade physics candidates in three separate schools within the Renfrew Division of Strathclyde Region. The tests took place in May - June 1977. The pupils were given approximately 1 hour to complete each test and were supervised by the class teacher. The pupils recorded their answers on mark-sense cards, which were then processed by computer in Jordanhill College of Education to obtain a detailed item-analysis for each test. Table 12 gives the details of the numbers of pupils involved in each test. 262 pupils sat both tests.

Table 12 - Number of pupils involved in each test.

	Momentum test				Energy test			
	S4	S5	S6	Total	S4	S5	S6	Total
School A	97	60	0	157	81	59	0	140
School B	33	33	22	88	32	35	18	85
School C	42	17	0	59	57	17	0	74
Totals	172	110	32	304	170	111	18	299

When the tests were being compiled, it was assumed that, due to the time a pupil would require to complete either test, it would only be possible for a pupil to do one or other of the two tests. Six anchor items were therefore inserted into both tests so that, by comparing the relative performance on these common items, we could judge the similarity of the respective test populations. As it turned out, however, the respective test populations were very similar, as Table 12 showed, and the anchor items were scarcely necessary. Not surprisingly, perhaps, there was no significant difference in performance on the two tests for these six anchor items.

The anchor items involved both momentum and energy, and so could reasonably be included in either test. For example, item 11 of the momentum test, which is also item 13 of the energy test, was as follows:-

"The kinetic energy of a 2 kg mass is 16 J. What is its momentum ?

A 2 kgm s^{-1} B 4 kgm s^{-1} C 8 kgm s^{-1}

D 16 kgm s^{-1} E 80 kgm s^{-1} "

Because the solution of such items involves two or more stages, they must be categorised as 'D' items.

Analysis of test results

Table 13 shows the distribution of marks for each school together with the overall marks distribution for the two tests. The same data is presented graphically in Figure 3 and Figure 4.

Table 13 - Summary of marks in each test

	Momentum test				Energy test			
	Sch A	Sch B	Sch C	Total	Sch A	Sch B	Sch C	Total
Highest score	39	37	33	39	39	37	31	39
Lowest score	6	3	12	3	6	8	8	6
Median	21	20	22	21	21	20	21	21
Arithmetic mean	22.1	21.4	22.5	22.0	20.8	20.2	20.9	20.7
Standard deviation	7.83	6.69	5.49	7.12	6.69	5.94	4.49	6.00

Fig. 3 - Distribution of scores on the momentum test

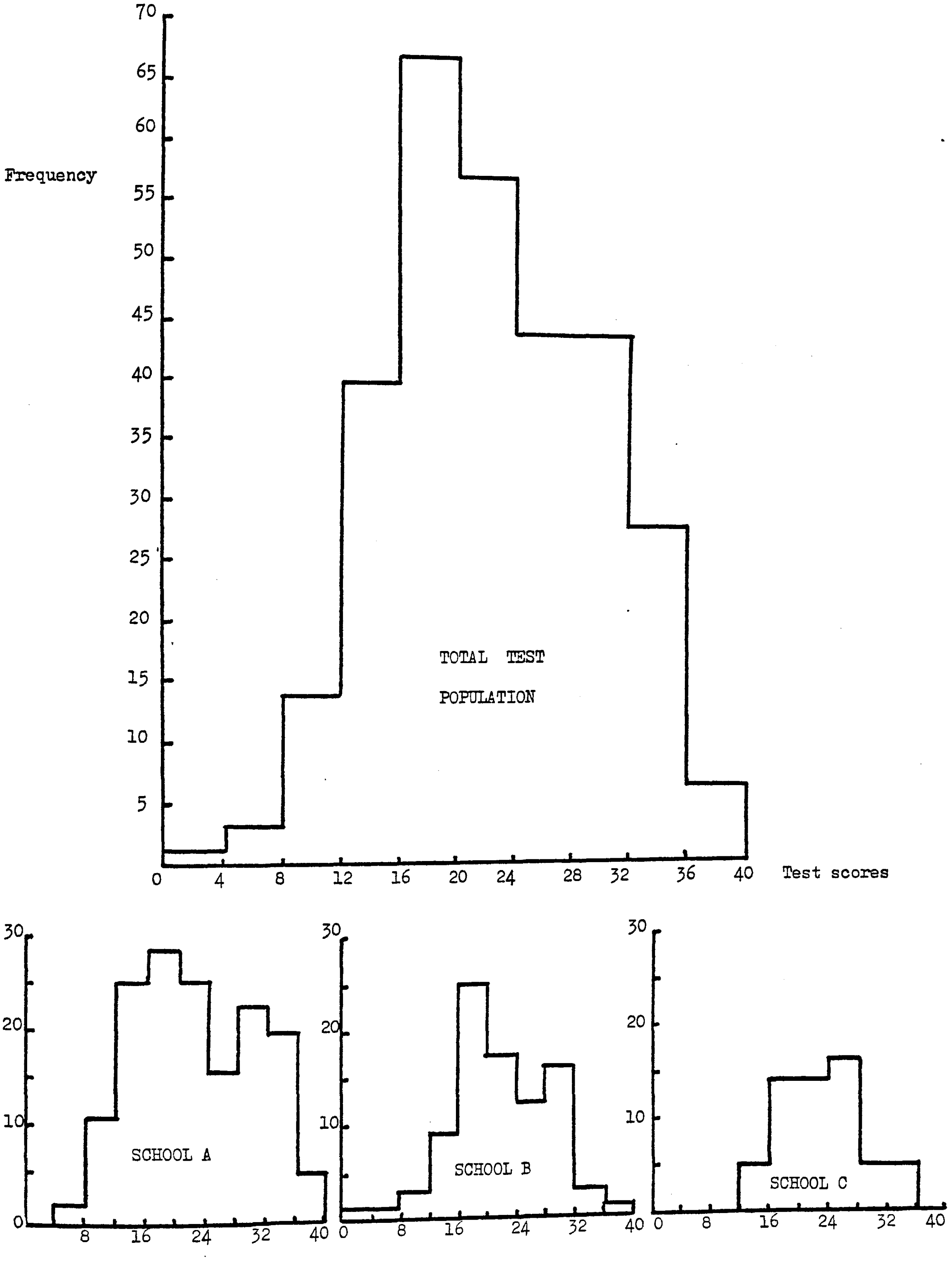


Fig. 4 - **Distribution of scores on the energy test**

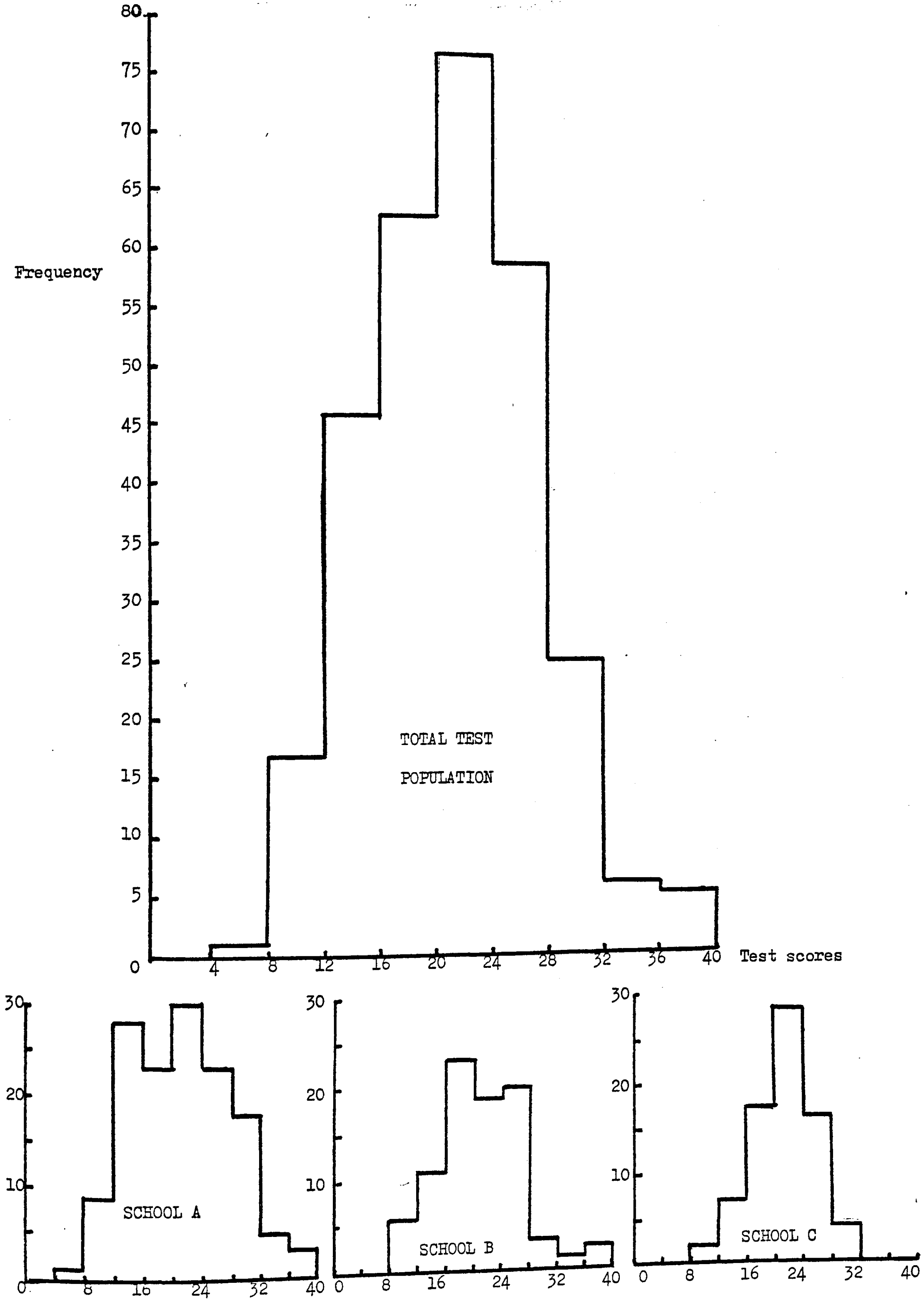


Table 14 - Mean scores of each year group on each test

	Momentum test				Energy test			
	S4	S5	S6	Total	S4	S5	S6	Total
School A	18.7	27.8	-	22.1	17.9	24.9	-	20.8
School B	17.2	22.5	26.0	21.4	17.4	20.5	24.5	20.2
School C	20.4	26.7	-	22.5	20.3	23.0	-	20.9
Total	18.8	26.1	26.0	22.0	18.5	23.5	24.5	20.7

Table 14 gives a summary of the pupils' performance in each test. As this table indicates, there is no significant difference in overall performance between the three schools. However, if we look at the mean scores of each year group on each test (Table 14), we get a very different impression. It becomes clear that there is a marked difference in performance when we compare the O-Grade pupils with the H-Grade pupils. We will discuss this difference in more detail later.

Table 15 gives a summary of the item analysis for the momentum test and Table 16 gives a similar summary for the energy test. In each table, the facility values (FV) and the point biserial correlations (PBC) are calculated for the respective test population. The criterion scores indicate, for each item, the average score (out of 40) of the group of pupils who had chosen each of the given responses. The key (correct response) for each item is indicated by'**'.

Table 15 - Summary of Item Analysis for Momentum Test

No.	FV	PBC	Criterion Scores					Distractors %					
			A	B	C	D	E	A	B	C	D	E	MISS
1	98	1	0	15	0	10	22	0	1	0	1	**	0
2	98	1	0	14	11	22	14	0	1	1	**	0	0
3	72	45	18	24	24	20	18	13	6	**	5	2	1
4	53	30	19	19	21	24	20	22	6	12	**	5	2
5	88	38	23	14	16	8	0	**	2	9	1	0	0
6	78	54	11	16	24	17	17	1	6	**	5	10	0
7	49	28	18	21	24	19	21	6	24	**	11	9	2
8	65	58	25	16	17	14	6	**	9	22	3	0	0
9	56	63	17	18	17	26	17	22	8	8	**	4	2
10	42	48	18	26	19	19	20	7	**	13	11	22	6
11	88	38	16	18	23	17	0	1	8	**	3	0	1
12	33	30	25	21	21	19	21	**	17	24	8	10	7
13	40	46	19	18	26	24	21	48	3	**	1	7	0
14	89	41	17	17	14	13	23	3	3	1	3	**	0
15	58	50	19	15	17	25	14	20	5	12	**	2	3
16	47	53	17	17	26	7	21	27	1	**	1	24	1
17	7	11	22	21	25	21	22	22	15	**	3	52	1
18	61	53	20	17	16	25	21	12	6	8	**	5	8
19	62	53	19	25	17	17	22	10	**	2	4	7	15
20	64	57	25	17	17	17	16	**	10	13	4	5	4
21	84	32	18	16	14	14	23	6	3	6	2	**	0
22	49	69	20	17	17	27	18	7	14	20	**	4	5
23	66	59	17	25	17	18	16	5	**	7	10	3	9
24	66	39	17	24	17	19	20	11	**	10	5	4	5
25	56	32	24	20	20	21	19	**	9	2	23	9	1
26	61	35	16	21	24	17	15	5	25	**	7	1	1
27	13	28	21	18	19	23	27	5	7	7	29	**	39
28	44	38	20	25	22	18	20	6	**	9	17	10	14
29	62	54	17	16	25	18	21	5	7	**	6	10	10
30	43	37	20	25	21	20	20	13	**	10	10	9	14
31	37	33	22	18	21	25	17	22	11	23	**	5	3
32	63	55	17	20	16	18	25	4	7	4	8	**	14
33	44	25	21	24	22	19	24	16	**	17	7	4	11
34	69	42	24	18	17	19	19	**	6	4	6	3	13
35	41	47	20	22	18	26	19	15	6	5	**	19	13
36	8	25	28	21	21	23	22	**	9	6	45	15	17
37	54	46	18	25	20	13	21	8	**	17	3	7	12
38	38	33	22	18	21	24	25	16	5	13	5	**	23
39	35	42	20	26	21	22	21	21	**	9	10	3	23
40	16	31	22	22	21	22	27	44	10	7	7	**	17

Table 16 - Summary of Item Analysis for Energy Test

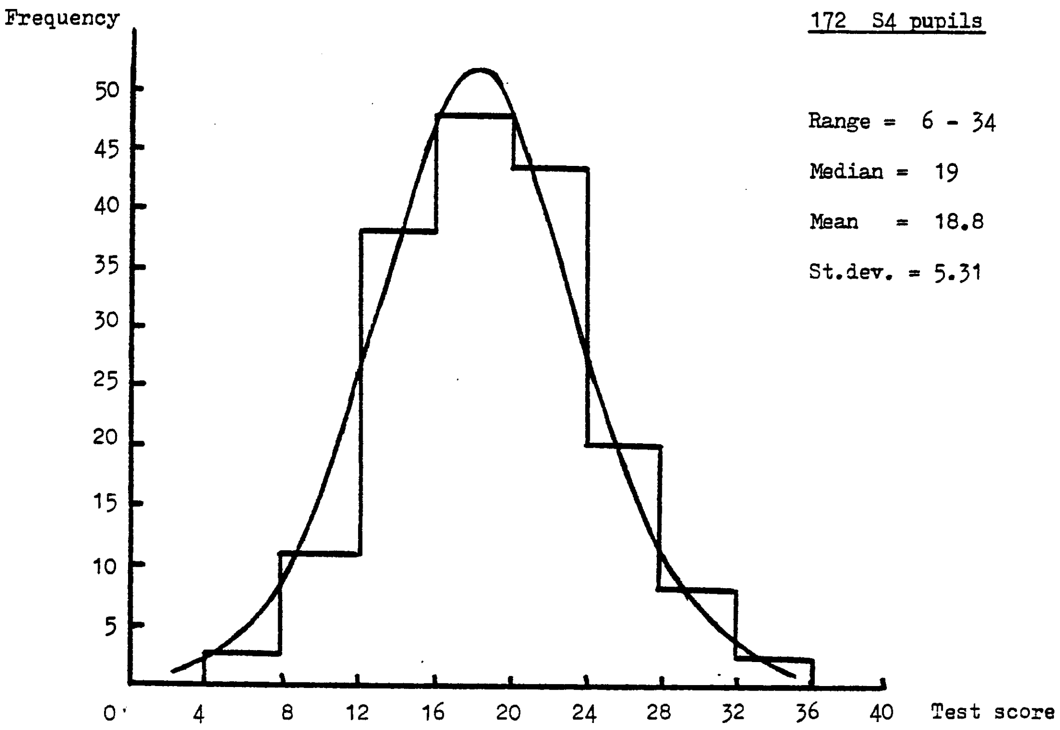
No.	FV	PBC	Criterion Scores					Distractors %					
			A	B	C	D	E	A	B	C	D	E	MISS
1	59	46	16	23	16	17	18	7	**	10	10	13	1
2	98	36	20	11	17	12	21	0	0	1	1	**	0
3	72	35	22	16	17	19	18	**	5	11	4	7	0
4	83	49	18	14	15	22	16	2	10	2	**	2	0
5	27	13	22	20	21	18	20	**	11	41	6	13	2
6	42	47	16	18	19	24	20	4	39	11	**	4	1
7	21	37	25	18	21	17	13	**	28	39	8	2	1
8	94	20	18	21	13	14	17	2	**	1	2	1	0
9	27	33	24	19	19	22	23	**	27	37	4	3	1
10	71	34	18	22	17	22	18	18	3	3	**	4	2
11	61	48	18	23	18	17	18	4	**	6	14	12	3
12	39	45	18	19	18	24	18	24	13	8	**	9	8
13	84	12	16	18	21	14	0	1	10	**	4	0	1
14	71	34	17	17	12	16	22	19	1	2	3	**	3
15	90	16	17	13	21	14	18	4	3	**	1	1	1
16	31	48	16	20	19	19	25	5	3	25	31	**	6
17	55	42	23	18	18	18	16	**	18	16	4	6	0
18	44	49	17	17	24	17	19	26	3	**	1	25	1
19	55	42	19	16	15	23	16	28	6	3	**	4	4
20	51	22	18	20	22	21	19	12	5	**	5	24	3
21	16	17	22	21	23	19	21	4	29	**	42	6	2
22	76	39	18	14	16	19	22	11	3	7	2	**	1
23	81	11	18	21	16	18	15	17	**	1	1	1	0
24	56	62	19	16	24	17	17	2	2	**	16	20	4
25	66	53	17	15	23	20	18	12	8	**	7	4	4
26	39	44	24	17	18	18	20	**	13	7	3	38	1
27	57	45	16	20	23	15	15	8	26	**	4	4	0
28	84	49	16	22	17	16	20	4	**	6	5	1	0
29	53	23	22	20	18	17	17	**	32	6	6	2	1
30	72	35	17	15	20	22	18	2	5	10	**	7	4
31	46	35	20	23	21	18	13	5	**	8	35	1	5
32	51	39	16	16	20	23	20	15	6	10	**	15	3
33	39	31	20	16	21	23	18	18	14	22	**	4	3
34	37	55	19	25	19	12	15	43	**	9	2	4	4
35	49	37	18	19	18	19	23	11	11	16	5	**	8
36	10	2	17	18	18	21	23	3	16	8	**	54	9
37	14	2	19	21	21	8	23	7	61	**	1	4	13
38	29	14	20	22	21	19	21	12	**	7	33	14	5
39	19	35	21	17	23	18	25	46	15	7	4	**	9
40	2	16	17	21	22	23	27	20	42	15	13	**	8

Discussion of results

An analysis of the results of the tests showed that there was very little significant difference in overall performance of the pupils from the three schools but, when the S4 results and the S5 results were considered separately, it became clear that the mean score of the S5 pupils was significantly greater than the mean score of the S4 pupils. This was true of all three schools in both tests. The mean scores for each test were given in Table 14. In all cases, the results were significant at the 0.05 level and, in seven out of eight cases, at the 0.01 level.

The distribution of test scores for the momentum test is shown in Figure 5. For both the S4 and S5 groups, the distribution is essentially normal, as indicated by the closeness of fit of a calculated normal curve to the original distribution. By drawing the S4 and S5 distributions separately, the significant increase in the mean score from S4 to S5 can clearly be seen. The same sort of information for the energy test is shown in Figure 6.

Fig. 5 - Distribution of scores on momentum test



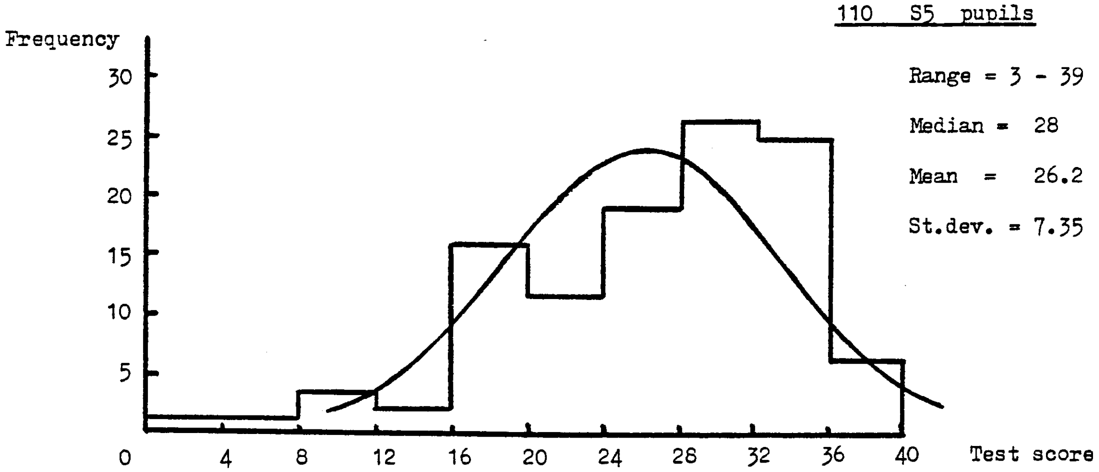
172 S4 pupils

Range = 6 - 34

Median = 19

Mean = 18.8

St.dev. = 5.31



110 S5 pupils

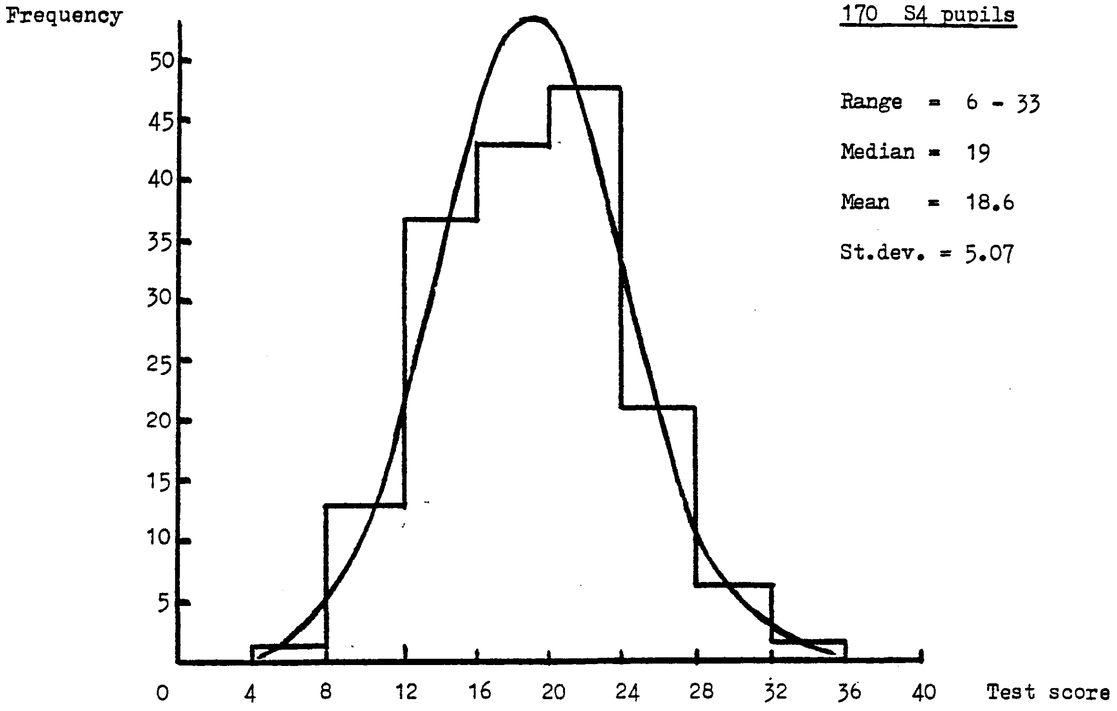
Range = 3 - 39

Median = 28

Mean = 26.2

St.dev. = 7.35

Fig. 6 - Distribution of scores on energy test



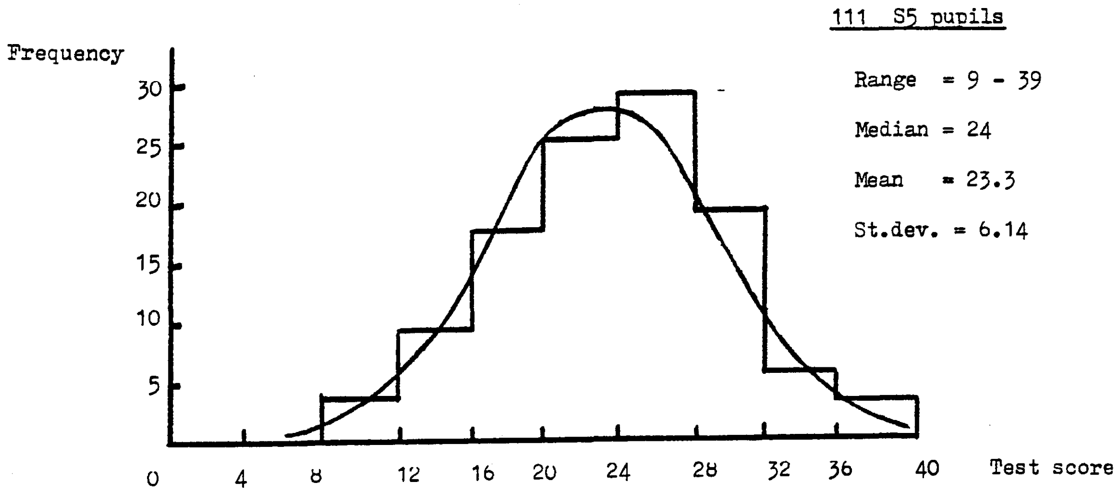
170 S4 pupils

Range = 6 - 33

Median = 19

Mean = 18.6

St.dev. = 5.07



111 S5 pupils

Range = 9 - 39

Median = 24

Mean = 23.3

St.dev. = 6.14

It is not immediately obvious why there should be such a marked improvement in mean score from S4 to S5 for both tests. One suggested explanation was that, since both tests contained items selected to test H-Grade objectives, only the S5 (H-Grade) pupils would be able to attempt all the items in each test and would therefore be expected to achieve a higher score than the S4 (O-Grade) pupils. Another suggested explanation was that the S4 group contained pupils from a much wider ability range than the other two groups. To put this another way, the less able pupils in physics are 'weeded out' by the O-Grade examination at the end of S4, leaving only the more able pupils in physics to continue to H-Grade in S5. While there is certainly a degree of truth in both these suggestions, neither of them can be accepted as a complete explanation for the following reasons :-

(1) A detailed item by item examination of the test results revealed that, for both tests, the S4 facility value of an item was consistently lower than the corresponding S5 facility value. Thus the lower mean score for S4 pupils is not solely due to their poorer performance on the specific items which test H-Grade objectives.

(2) For each test, the items arranged in order of difficulty for S4 pupils were rank correlated with the same items arranged in order of difficulty for S5 pupils. For the momentum test, the correlation coefficient was 0.86, while for the energy test it was 0.94. This would indicate that, in either test, the relative difficulty of the items is much the same for either group.

(3) Of the 172 S4 pupils involved in the momentum test (or the 171 S4 pupils involved in the energy test) only 6 pupils (or less than 4%) have subsequently failed to obtain at least

a 'C' pass * in O-Grade physics. Thus the proportion of the S4 group who are 'weeded out' by the O-Grade examination is really quite small. Also, in the schools involved in the tests, the vast majority who obtain a 'C' pass in O-Grade physics will continue with physics in S5. Thus the ability range within the S5 group may not be markedly different from that in the S4 group.

(4) Some of the original S4 group were retested, using the same tests, approximately one year later when they were in S5. The retest results showed that, for the momentum test, their mean score had increased, between S4 and S5, from 20.7 to 29.8, while, for the energy test, their mean score had increased from 20.6 to 27.8. Although the 40 pupils who were retested do not constitute a random sample of the original population, the proportionate increase in their mean test score from S4 to S5 almost exactly matches, for each test, the corresponding increase in mean test score of the original S4 and S5 groups.

It would appear, from the evidence available, that a pupil's ability to handle the concepts of momentum is related to the age and experience of the pupil in the sense that the older, more experienced pupil may be expected to score more highly in a multiple-choice test involving these concepts. In Piagetian terms, we might explain this by a greater percentage of H-Grade pupils being at the formal operational level of cognitive development. In Ausubelian terms, we might explain this by the H-Grade pupils'

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* Pupils are awarded an A- E grade in O-Grade physics as follows:-
A $\geqslant$ 70%, B = 60-69%, C = 50 - 59%, D = 40 - 49%, E = 30 - 39%. A, B and C are generally considered as 'pass' grades.

cognitive structure being more elaborate, and more meaningfully structured. While we prefer the latter explanation, we found little empirical evidence in the test results which would clearly substantiate or refute one or other explanation. We did find some evidence, however, to indicate that, in items which involved definitions or substituting numbers into a formula, there was often very little difference in scores between the O-Grade group and the H-Grade group. The items which showed the greatest difference in mean scores were, in general, the ones which required a more meaningful understanding of the concepts and ones which required the manipulation of relationships between concepts.

Perhaps the most useful single statistic for any given test item is its facility value (F.V.) In terms of their overall F.V., the test items may be divided into three groups - easy, average and difficult items. 'Easy' items were those with an overall F.V. greater than 0.7 and 'difficult' items were those with an overall F.V. less than 0.3. Recalling that H-Grade pupils did significantly better on both tests than O-Grade pupils, the H-Grade F.V. and the O-Grade F.V. for each test item was calculated. Each of the three previous groups of items can then be divided into sub-groups by considering the difference between the H-Grade F.V. and the O-Grade F.V. for each individual item. Table 17 shows the overall pattern which results from this analysis.

Table 17 - Momentum and energy test items grouped by facility value (F.V.)

Overall F.V.	'Easy' Items F.V. > 0.7		'Average' Items 0.7 ⩾ F.V. ⩾ 0.3			'Difficult' Items F.V. < 0.3	
Difference between O-Grade F.V. and H-Grade F.V.	0.2 - 0.1	< 0.1	> 0.3	0.3 - 0.1	< 0.1	0.2 - 0.1	< 0.1
Momentum test items	3,6	1,2,5,11*, 14,21*	10,16*,19, 20,22,23, 24,28,29, 32,35	4,8,9,12,13, 15,18,30, 31*,33,34, 37,38,39	7,25,26*	27,36,40*	17
Energy test items	10,13*,14, 22*	2,3,4,8, 15,23,28, 30	34	1,6,12,16, 17,18*, 19, 24,25,27*, 31,32,35	11, 20, 26, 29, 33*	7,9,21,37	5,36,38,39* 40

* = Anchor Items

From a consideration of the items which appear in the 'easy' group, it may be inferred that certain objectives given in Table 7 are likely to be achieved by most pupils. For example:-

(i) Pupils can recall and apply the relationships $p = mv$ and $E_k = \frac{1}{2} mv^2$. This ability was demonstrated explicity in such items as

Item 2-Momentum Test Category B
O-Grade F.V. = 0.97 H-Grade F.V. = 0.99

"The masses and velocities of five moving trolleys are given below:-

(i) 4 kg moving at 6 m s^{-1}
(ii) 5 kg moving at 5 m s^{-1}
(iii) 6 kg moving at 4 m s^{-1}
(iv) 3 kg moving at 9 m s^{-1}
(v) 8 kg moving at 3 m s^{-1}

The trolley with the greatest momentum is
A.(i) B.(ii) C.(iii) D.(iv) E.(v) "

Item 28 - Energy Test Category D
O-Grade F.V. = 0.79 H-Grade F.V. = 0.88

"A 2 kg trolley moving at 2 m s^{-1} collides with a 2 kg stationary trolley. They stick together and move off with a velocity of 1 m s^{-1}. In this collision the kinetic energy lost is -

A. 1J B.2J C.3J D. 4J E. 8J "

The following anchor items also confirmed this ability.

Item 11 - Momentum Test Category D
O-Grade F.V. = 0.86 H-Grade F.V. = 0.91

"The kinetic energy of a 2 kg mass is 16J. What is its momentum?

A. 2 kg m s^{-1} B.1 kg m s^{-1} C.8 kg m s^{-1}
D. 16 kg m s^{-1} E. 80 kg m s^{-1} "

Item 21 - Momentum Test Category D
O-Grade F.V. = 0.81 H-Grade F.V. = 0.82

"If the momentum of a ball of mass 0.5 kg is 5.0 kg m s^{-1}, its kinetic energy is

A. 2.5J B. 5.0J C. 6.25J D. 12.5J E. 25J "

(ii) Pupils can apply the conservation of momentum relationships in cases where the collision involves no change of direction or where the direction of motion after the collision is given. This ability was demostrated in such items as

Item 5 - Momentum Test Category B
O-Grade F.V. = 0.85 H-Grade F.V. = 0.92

"A mini-car of mass 400 kg, travelling at 20 m s^{-1}, hits another car of mass 600 kg which is at rest on an icy road. The cars lock, bumper to bumper. Their common velocity immediately after the collision is

A. 8 m s^{-1} B. 12 m s^{-1} C. $13\frac{1}{3}$ m s^{-1}

D. 30 m s^{-1} E. 50 m s^{-1} "

Item 6 - Momentum Test Category B
O-Grade F.V. = 0.71 H-Grade F.V. = 0.86

"A ball of mass 5 kg travelling at 4 m s^{-1} collides with a stationary ball of mass 3 kg. After the collision the 5 kg ball is still travelling in the same direction, but at 1 m s^{-1} The 3 kg ball is now also travelling in this direction, with a velocity of

A. 1 m s^{-1} B. 3 m s^{-1} C. 5 m s^{-1}

D. $\frac{25}{3}$ m s^{-1} E. $\frac{20}{8}$ m s^{-1} "

(iii) Pupils can recall the relationship 'energy = force x distance' and can apply it to the calculation of the gain in E_k or E_p in simple numerical cases.

This ability was demonstrated in such items as

Item 3 - Energy Test Category A

O-Grade F.V. = 0.69 H-Grade F.V. = 0.78

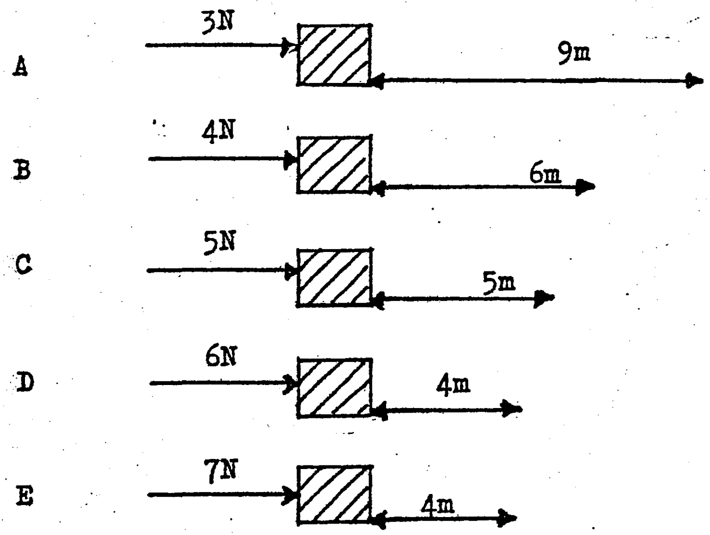
"Which expression represents energy?

A force x distance
B mass x velocity
C force x time
D mass x acceleration
E force x velocity "

Item 14 - Energy Test Category B

O-Grade F.V. = 0.66 H-Grade F.V. = 0.77

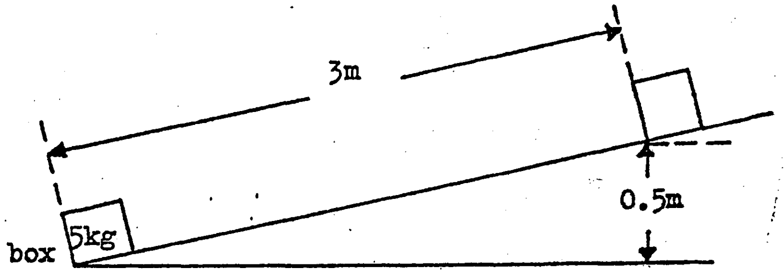
"Five bodies, initially at rest, are acted on by five different unbalanced forces through the distances shown in the following diagram. Which body gains the most kinetic energy?"



Item 15 - Energy Test. Category B.

O-Grade F.V. = 0.88 H-Grade F.V. = 0.92

"A box of mass 5 kg is pulled up a slope



Neglecting friction, the potential energy gained is

A. a.5J B. 15J C. 25J D. 150J E. 175J "

We now consider items which appear in the 'difficult' group in Table 15. If items in the 'easy' group showed what the pupils did understand, then it would be reasonable to assume that items in the 'difficult' group showed what the pupils did not understand. Moreover, it was noted that 75% of the items appearing in the 'easy' group were category A or category B items, while 85% of the items appearing in the 'difficult' group were category C or category D items, We might suspect, therefore, that the reason why the pupils found these items difficult was, in some way, associated with their inability to select the appropriate concept or principle or to manipulate more than one concept or principle at the same time. This sort of ability would certainly be required to answer such items as:

Item 9 - Energy Test Category C

O-Grade F.V. = 0.22 H-Grade F.V. = 0.33

"Two bodies P, of mass m, and Q, of mass 2m, are moving in the same direction. Each has the same kinetic energy. If the same decelerating force is applied to each, how do the stopping distances S_p and S_q compare ?

A. $S_p = S_q$ B. $S_p = 2s_q$ C. $S_p = \frac{1}{2}s_q$ D. $S_p = 4s_q$

E. $S_p = \frac{1}{4}s_q$ "

Item 38 - Energy Test. Category D
O-Grade F.V. = 0.31 H-Grade F.V. = 0.25

"Two moving bodies, P and Q, have the same momentum but the kinetic energy of P is twice the kinetic energy of Q. The mass of P is :

A. one quarter the mass of Q
B. one half the mass of Q
C. the same as the mass of Q
D. twice the mass of Q
E. four times the mass of Q "

The item analysis provides an important clue as to what is happening. The pattern of responses shows that, although all the distractors are functioning, at least one of these distractors is attracting an unduly large percentage of the total responses, and is proving more popular than the key response. For example, in item 9 in the energy test, the pattern of responses was as follows:

	A	B	C	D	E
O-Grade	22	34	35	4	4
H-Grade	33	17	41	5	2

The popularity of response C (and also response B at O-Grade) indicates that the real source of the pupils' difficulty lies in their assumption that the masses of P and Q are somehow involved. In fact the masses of P and Q are redundant information in this item.

It is certainly true that teachers impress on their pupils that all the information given in the stem of an item is essential information. Pupils seldom meet items with redundant information, so they find it difficult to ignore such information, unless they can analyse the situation well enough to convince themselves that the information is really redundant. In the above item, it would appear most O-Grade pupils failed to recognise the principle involved.

The pattern of responses for item 38 of the energy test showed that response D attracted 41% of H-Grade responses and 29% of O-Grade responses. To explain the popularity of this response we might assume that the pupils interpreted 'same momentum' as implying 'same speed', but a more likely explanation would be that they recognised intuitively that the correct response was either B or D and simply guessed. If we accept the latter explanation, then the pupils who gave response B were also guessing in most cases. We suspect that the rigorous logical analysis required in this item was not carried out by many pupils.

The pattern of responses can often provide useful diagnostic information about the nature of the pupils' understanding. For example, item 7 of the energy test showed the following pattern of responses.

	A	B	C	D	E
O-Grade	16	34	39	8	3
H-Grade	30	23	35	9	3

Item 7 - Energy Test   Category D

O-Grade F.V. = 0.16   H-Grade F.V. = 0.30

Two masses, m and 2m, moving along a frictionless horizontal surface, collide and come to rest. Before the collision the speed and kinetic energy of the masses were -

	Speed	Kinetic Energy
A	m had greater	m had greater
B	both had same	2m had greater
C	m had greater	both had same
D	both had same	both had same
E	2m had greater	both had same

We can get information about the pupils' knowledge of both momentum and kinetic energy from this item. We can see from the pattern of responses that responses A, B and C are much more popular than responses D and E. This suggests that most pupils have correctly applied the momentum information to deduce that, before the collision, m had the greater speed (responses A and C). Comparing the responses to B and D, we see that most pupils have correctly concluded that, if the masses both had the same speed, then the 2m mass had greater kinetic energy. The pattern of responses leads us to conclude that, while only a minority of pupils could do both parts, most pupils could do either the momentum part or the energy part.

The difficulty in this item for most pupils is combining the momentum and the kinetic energy parts. The same difficulty is evident in items 38 and 39 of the energy test.

We have already considered item 38. In item 39, by far the most common response was A, which would be a correct response <u>if we considered only momentum being conserved</u>. Response B, which was almost as popular as the key response E, would be a correct response <u>if we only considered kinetic energy being conserved</u>.

We suspect, therefore, that a possible cause of difficulty is the amount of information which the pupil has to keep in mind when solving the problem. This may be explained in terms of 'information overload' of the working memory, as Johnstone (74) has suggested. We will look for further evidence of this in other items.

Item 5 of the energy test gave very disappointing results at both O-Grade and H-Grade.

Item 5 - Energy Test Category C

O-Grade F.V. = 0.29 H-Grade F.V. = 0.27

"A joule is the energy required to

A. move a 1kg mass 1m against a friction force of 1N
B. give a stationary 1kg mass a velocity of 1m s^{-1}
C. raise a 1kg mass through a vertical distance of 1m
D. bring a 1kg mass moving at 1m s^{-1} to rest in 1m
E. accelerate a 1kg mass at 1m s^{-2} for 1m "

The pattern of responses to this item was as follows:-

	A	B	C	D	E
O-Grade	29	12	39	4	14
H-Grade	27	10	38	9	14

The most popular response, C, clearly involves potential energy and this may explain its popularity. To see why response C is wrong, the pupil must argue that the 1kg mass has a weight of 10N and thus the energy involved is 10Nm or 10J. Similarly, to rule out response B, the pupil must argue that the 1kg mass moving at 1m s^{-1} has gained an amount of kinetic energy given by
$E_k = \frac{1}{2}mv^2 = \frac{1}{2}(1)(1)^2 = 0.5J$.
Response D is wrong for the same reason, and the 'in 1m ' is redundant information. Response E is wrong because it is a definition of force, not energy,

---

It has since been pointed out that response E is, in fact, correct and that the item has two correct answers.

although the additional phrase 'for 1m' would make some pupils hesitate to rule it out. Finally the correct response, A, contains redundant information - the '1kg mass' can be ignored. All the responses, except C, assume that the motion is taking place in a horizontal plane.

When we consider in detail what may be involved in answering this item, the possibility of 'information overload' becomes obvious.

We have mentioned the problem of redundant information appearing in the stem of an item. Item 27 of the momentum test illustrates the opposite problem. Here essential information - the duration of the collision - was not given in the stem. As a result, there is no correct answer, although response E was taken to be the key in the item analysis program.

We now consider the remaining group of test items which had a F.V. between 0.3 and 0.7. As Table 17 shows, about one quarter of these 'average' items turned out to have a difference between the O-Grade F.V. and the H-Grade F.V. of more than 0.3, Most of these items occurred in the momentum test and the most likely explanation is that these items are testing specifically H-Grade objectives. For example :

Item 20 - Momentum Test   Category B
O-Grade F.V. = 0.50   H-Grade F.V. = 0.85

"A mass of 2kg is brought to rest in 0.1s by a constant force of 1N. What was the velocity of the mass before the force began to act?

A. 0.05m s^{-1} B. 0.1m s^{-1} C. 0.2m s^{-1} D. 10m s^{-1}
E. 20m s^{-1} "

Item 29 - Momentum Test   Category B
O-Grade F.V. = 0.47   H-Grade F.V. = 0.82

"The momentum of a trolley of mass 4kg is changed from 6kg m s^{-1} to 24 kg m s^{-1} by a constant force of 3N. For how long does the force act on the trolley to cause this momentum change?

A. 1.5s   B. 2s   C. 6s   D 8s   E 24s   "

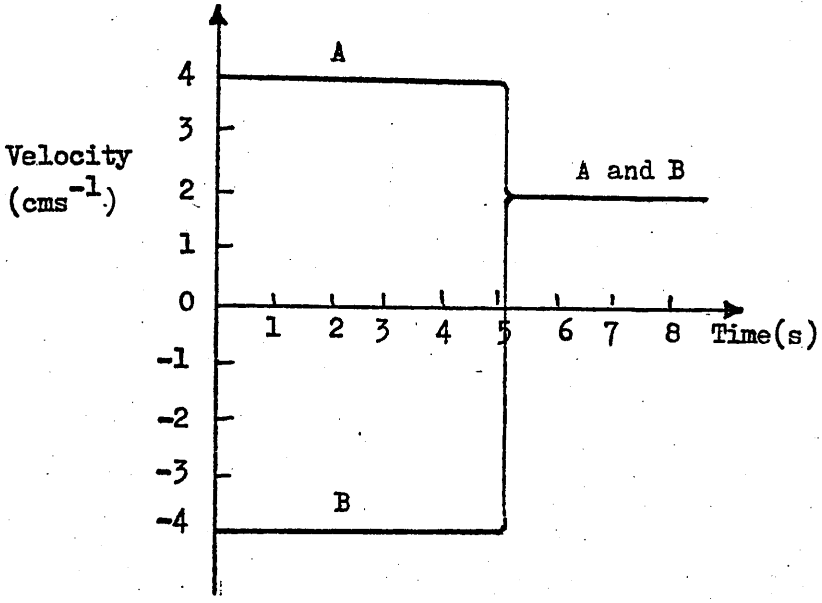
If these items are testing specifically H-Grade objectives, then we might wonder why the O-Grade pupils can do them at all. In fact, the O-Grade pupils can get to the answer by using the relationship '<u>force = mass x acceleration</u>' and substituting the resulting acceleration into one of the equations of motion. (It may be of interest to note that these equations of motion are not required for O-Grade, but all three schools involved taught these equations at O-Grade). The H-Grade pupils could also use this method, but most of them would apply the <u>impulse</u> relationship (i.e. $F \Delta t = \Delta mv$)

The high H-Grade F.V. for these items would indicate that the use of the impulse relationships may be the more successful method. In passing, we would point out that, for problems involving '<u>force</u>' and '<u>time for which the force acts</u>', the concept of '<u>impulse</u>' is really just a convenient 'chunking' strategy which avoids the need to calculate the acceleration as an intermediate step.

It should not be assumed that all the H-Grade objectives are being achieved to the same high degree. The following items indicate that there are difficulties in interpreting graphs and in momentum conservation in two dimensions.

Item 10 - Momentum Test   Category C
O-Grade F.V. = 0.28   H-Grade F.V. = 0.61

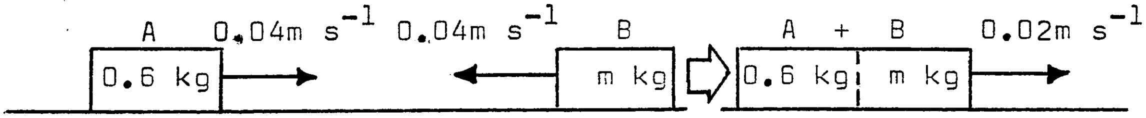
"The velocity-time graph shows a collision between two trolleys A and B on a level surface



If the mass of trolley A is 0.6kg, what is the mass of trolley B?

A. 0.15kg B. 0.2kg C. 0.3kg D. 0.4kg E. 0.6kg "

The amount of information contained in the above graph is really quite surprising. It tells us that this was an inelastic collision, which we could represent by a more conventional diagram :-



It tells us more than this however.
It tells us that the duration of the collision was 0.1s. From this we could estimate the average force acting during the collision.

It also gives us all the information we would need to estimate the loss in kinetic energy during the collision.

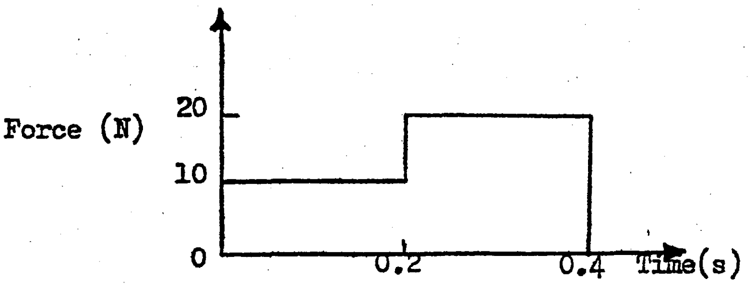
The problem for the pupil is one of sifting all this information to pick out what he needs to answer the question. The one essential fact is that the increase in B's velocity is three times the decrease in A's velocity. Thus, since momentum is conserved, the mass of B is one third the mass of A.

Here again the problem may be 'information overload'. The pupil may be swamped by the amount of information contained in the graph, most of which is redundant.

Item 33 - Momentum Test   Category C

O-Grade F.V. = 0.35   H-Grade F.V. = 0.54

"The graph shows how the force acting on a mass of 2kg varies with time.



If the mass had an initial velocity of 1m s^{-1}, what is its velocity after 0.4 seconds?

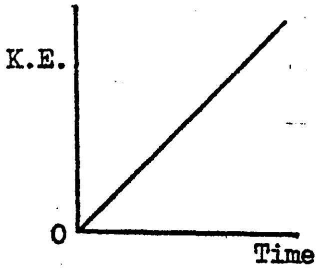
A. 3m s^{-1} B. 4m s^{-1} C. 5m s^{-1} D. 6m s^{-1} E. 7m s^{-1} "

Item 34 - Energy Test   Category C

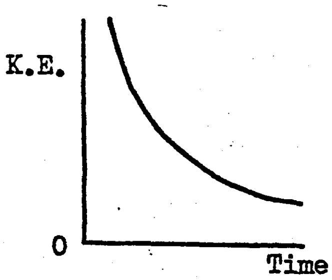
O-Grade F.V. = 0.22   H-Grade F.V. = 0.59

A body starts from rest and moves with uniform acceleration. The kinetic energy-time graph for its motion is

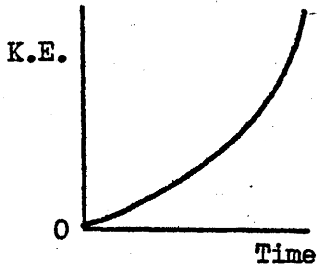
A



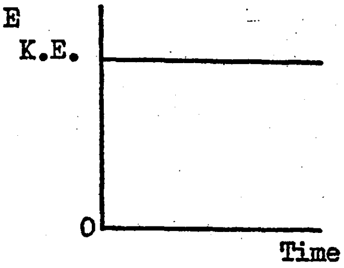
D



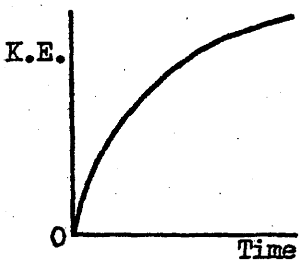
B



E



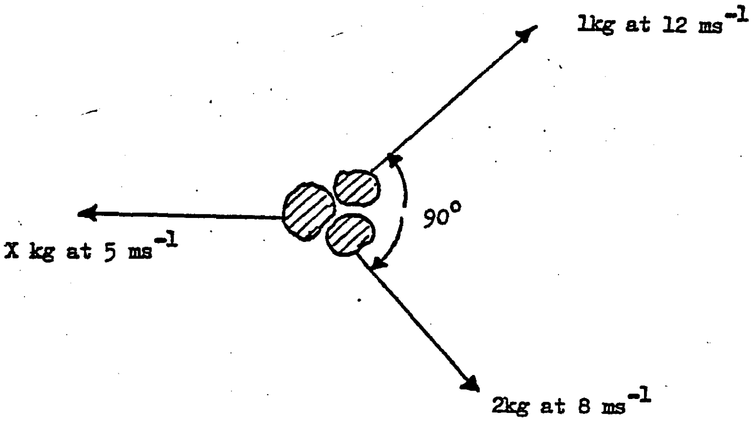
C



<u>Item 39 - Momentum Test Category D</u>

<u>O-Grade F.V. = 0.26 H-Grade F.V. = 0.51</u>

"An explosion blows a rock into three parts as shown in the diagram



What is the mass of fragment X ?

A. 3kg B. 4kg C. 5kg D. 6kg E. 7kg.

We did not anticipate that the O-Grade pupils would be able to answer items involving conservation of momentum in two dimensions, and other such topics which were uniquely H-Grade. We were not therefore surprised to note that these items were generally omitted by O-Grade pupils. The O-Grade F.V. quoted for these items is, therefore, not very relevant, since it is artificially depressed by the large number of 'nil' responses. A low O-Grade F.V. for some items is an indication of unfamiliarity with the topic rather than any real difficulty in understanding the topic. We can illustrate this by the following item, which is testing <u>recall</u> of an H-Grade objective.

<u>Item 19 - Momentum Test</u> <u>Category A</u>
<u>O-Grade F.V. = 0.47</u> <u>H-Grade F.V. = 0.79</u>

"An impulse applied to a body of mass m increases its speed from v_1 to v_2 without change of direction. The magnitude of the impulse is given by the expression :-

A. $mv_1 + mv_2$

B. $mv_2 - mv_1$

C. $\frac{m}{v_1 + v_2}$

D. $\frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2$

E. $\frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$ "

For a particular group of O-Grade pupils, the pattern of responses to the above item was:-

A	B	C	D	E	MISS
6	18	0	0	6	70

One year later, the same group of pupils, now H-Grade, gave a very different pattern of responses :-

A	B	C	D	E	MISS
12	82	0	0	6	0

There are items, of course, where O-Grade pupils should be able to do just as well as H-Grade pupils. In such cases, the difference in O-Grade F.V. and H-Grade F.V. is a true reflection of some variation in the level of understanding between the two groups.

For example, O-Grade pupils do not seem to appreciate that momentum is a vector quantity. In both the following items, the most popular O-Grade response was response A which takes no account of the vector nature of momentum.

Item 13 - Momentum Test   Category B

O-Grade F.V. = 0.28   H-Grade F.V. = 0.58

"A rubber ball of mass 0.25kg is thrown perpendicularly against a wall with a speed of 10m s^{-1} and rebounds with the same speed. The change in momentum of the ball is

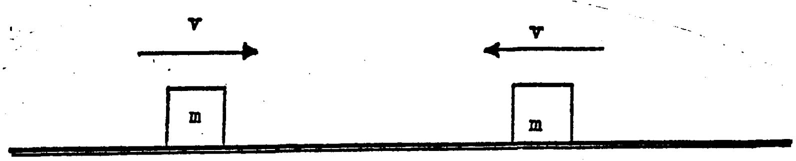
A. zero B. 2.5kg m s^{-1} C. 5 kg m s^{-1}

D. 10 kg m s^{-1} E. 20 kg m s^{-1}

Item 16 - Momentum Test   Category D

O-Grade F.V. = 0.35   H-Grade F.V. = 0.66

"Two bodies, each of mass m, have speeds v as shown



What is the total momentum and total kinetic energy of the two bodies?

	momentum	kinetic energy
A	2mv	mv^2
B	mv^2	2mv
C	0	mv^2
D	mv^2	0
E	0	0

It would also appear that O-Grade pupils have not fully appreciated that kinetic energy depends on the square of the speed. This emerges when we look at the pattern of responses to such items as:

Item 6 - Energy Test   Category B
O-Grade F.V. = 0.34   H-Grade F.V. = 0.51

"The kinetic energy of a bullet fired with velocity v is 2J. What is the kinetic energy of the same bullet fired with velocity 4v?

A. 4J   B. 8J   C. 16J   D. 32J   E. 64J "

46% of O-Grade pupils chose response B, presumably arguing that the kinetic energy varies as the speed.

(To digress for a moment, we were asked by a colleague why, in this item, were the velocities given as v and 4v. Would it not have been simpler to use actual numerical values? We were inclined to agree until we thought about the magnitude of these velocities. Would it really be simpler to talk about velocities of, say, $50m\ s^{-1}$ and $200m\ s^{-1}$? Our colleague then added that "most pupils would not think they were allowed to, say, make v = 1 ".)

Some pupils think that, in an elastic collision, only momentum is conserved. This was clear from the pattern of responses to an item such as :-

Item 27 - Energy Test Category D

O-Grade F.V. = 0.48 H-Grade F.V. = 0.64

"In an elastic collision between two bodies, what changes occur in their total kinetic energy and total momentum?

	Total kinetic energy	Total momentum
A	decreases	decreases
B	decreases	no change
C	no change	no change
D	no change	decreases
E	decreases	increases

31% of the O-Grade group and 24% of the H-Grade group chose response B.

The problem may be the word 'total'. For some pupils the 'total' energy is the 'total kinetic energy', for others it is the 'total potential energy'.

Item 16 - Energy Test Category D

O-Grade F.V. = 0.24 H-Grade F.V. = 0.39

"A stone of mass 0.2 kg is thrown upwards from a point 30m above the Earth's surface at an angle of 30° to the horizontal. It is released with a speed of 20m s^{-1}. What is the total energy of the stone at the moment of release?

A. 6J B. 10J C. 40J D. 60J E. 100J

Here the distractors C and D proved to be just as popular as the key E.

Conclusion

The cumulative evidence from the pupil tests suggests that the pupils have a good grasp of the fundamental definitions and can apply the basic relations (e.g. $p = mv$, $E_k = \frac{1}{2}mv^2$, $E_h = mgh$ and $F\Delta t = m\Delta v$) in simple situations. The problem arises when they have to progress beyond what can be rote learned. They are much less capable of solving problems where they have to recognise the principle to be applied or have to juggle with several different relationships. An important factor would seem to be the sheer complexity of the situation, in terms of the 'information content'. The significant improvement in performance between O-Grade and H-Grade may be due to the pupils becoming more proficient at reducing the 'information content' of the problem.

A detailed item analysis of the pupil's responses in a multiple choice test can provide useful diagnostic information about the pupil's level of conceptual understanding. The teachers, however, do not have the time to carry out such an analysis at each stage of the learning sequence. A more practical alternative is required, which will provide rapid feedback, to both teacher and pupil, about the pupil's grasp of a particular concept rather than his ability to solve problems involving several concepts or relationships between concepts.

We will develop this point further in the next chapter.

CHAPTER 5 - THE DESIGN OF THE TEST MATERIAL

Introduction

We now come to what we would consider is the main part of our investigation. In the session 1979-80, we carried out a large scale survey of pupils' (and students') understanding of concepts in mechanics, using specially devised test material. This material was revised in the light of the results obtained from the field trials, and, in the session 1980-81, the revised material was tested in twenty separate schools throughout Scotland.

Details of the testing procedures and an analysis of the results obtained will be given in subsequent chapters. In this present chapter, we will describe how the test material came to be written.

We will start by considering some of the problems involved in assessing conceptual understanding. We will explain why we thought it necessary to devise a new objective technique for obtaining specific information about the pupils' conceptual understanding. We will then describe some of the practical and theoretical considerations which influenced our design of the test material. Finally we will describe briefly the form of the test material which was used in the 1979-80 trial.

The problems involved in assessing a pupil's understanding of a concept.

We could see at least four problems in"assessing a pupil's understanding of a concept" :

(i) the problem of deciding what attributes of the concept are to be considered

(ii) the problem of deciding what factors about the pupil should be considered

(iii) the problem of deciding what is implied by the term 'understanding'

(iv) the problem of actually assessing the pupil's degree of 'understanding' of the concept.

All of these problems could be discussed at length, and each of them could well be a suitable subject for further detailed research. For the purposes of the present investigation, we simplified the situation by making some fairly arbitrary decisions about the first three problems on the list. This allowed us to concentrate our attention on the problem of actually assessing the degree of 'understanding'.

(1) We proposed, initially, that the concepts involved should be the ones which had been identified by the early study of Johnstone and Mughol (1) as being 'difficult' concepts for pupils in secondary schools. This, however, was not quite as simple as it might appear. The Johnstone and Mughol study, as explained in chapter 3, used a list of topics, rather than concepts, to assess the subjective level of difficulty. Thus the pupils reported that they found "the idea of conservation of momentum" a difficult one to understand. Was it the concept of 'conservation' they found difficult, or was it the concept of 'momentum'? Similarly, when the pupils reported difficulty with "the difference between energy and power", did their difficulty involve the concept of 'energy' or the concept of 'power' or did it specifically involve the relationship between these quantities? We had some difficulty in deciding exactly what concepts

the Johnstone and Mughol study had specifically identified as 'proving troublesome', but eventually decided upon the concepts of '<u>momentum</u>' and '<u>energy</u>'.

In the two previous chapters, we described two preliminary studies which we carried out to clarify some points of detail arising from Johnstone and Mughol's earlier work, as well as to collect further empirical data relating to the concepts of momentum and energy, since these two concepts were involved in the 'difficult' topics identified by the previous work. The results of these preliminary studies confirmed, for example, that the teachers did not rate the concept of 'power' as an essential concept for the understanding of energy, neither was there any significant difference in overall performance in the pupil tests on items relating to 'the difference between energy and power' and on items relating to 'the idea of kinetic and potential energy'. We feel justified, therefore, in not including the concept of 'power' in our main investigation.

The results of the teacher questionnaire, however, showed quite clearly that, in the teacher's opinion, the pupils' understanding of the concepts of momentum and energy involved various other 'essential' concepts. In particular, the concept of '<u>force</u>' was considered to be of particular importance in developing the understanding of both momentum and energy. One College lecturer commented that 'momentum is important because it connects the unbalanced force and the <u>time</u> for which it is acting, while energy is important because it connects the unbalanced force and the <u>distance</u> through which it acts'.

This view was confirmed by reference to the published syllabuses (2), where it is specifically stated that, at H-Grade, the teacher should "revise F = ma and relate (force) to rate of change of momentum". The published list of specific objectives for O-Grade (86) include, for the concept of energy, the objective that "pupils should acquire the ability to recall that the product of a force and the distance moved along its line of action is a measure of the work done and of the energy transferred." Many of the items included in the pupil tests, described in chapter 4, contained specific reference to the concept of force. If we look at the questions set in recent S.C.E. O-Grade and H-Grade examinations, we see the same sort of pattern.

The previous research had not looked closely at the concept of force. The one topic on Johnstone and Mughol's original list of 23 topics which mentioned force ("idea of uniform motion (body can maintain uniform motion without some unbalanced force to keep it moving)") was rated as 'difficult', but the reported difficulty clearly relates only to Newton I. There was not a topic on the original list which related to either Newton II or Newton III. From our own experience, we would suspect that any topic relating to Newton III (e.g. "action = - reaction") would have been rated as 'difficult'.

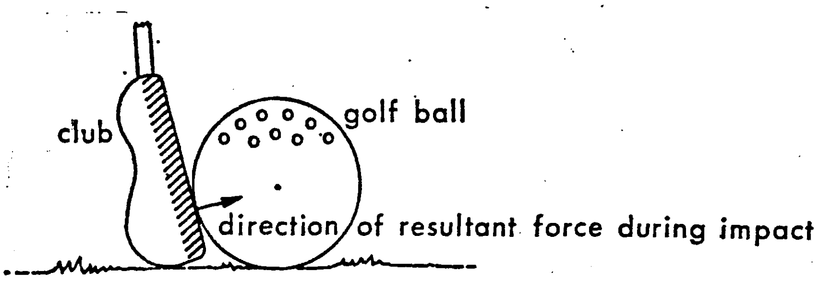
We decided, therefore, in view of the evidence quoted above, that in the next stage of our investigation we should examine the pupils' understanding of the concept of force as well as the concepts of momentum and energy.

In the S.C.E. physics syllabus, the concept of '<u>impulse</u>' is introduced at H-Grade, when Newton III is related to the law of conservation of momentum. In the questionnaire, the teachers did not consider that impulse was a particularly important concept, but, on the other hand, a question involving impulse is likely to appear almost every year in the S.C.E. H-Grade Paper II (e.g. 1980 Q2, 1978 Q1, 1977 Q3, 1976 Q2, 1975 Q3). Since impulse is so closely linked to both force and momentum (impulse = force x time and impulse = change of momentum), it seemed reasonable to include impulse, as well as force, in the next stage of the investigation.

In our opinion, the concept of impulse is a useful 'chunking' concept which, by combining the separate concepts of force and time into a single concept, enables the pupil to solve particular types of problem in mechanics in a single step. Consider, for example, the following problem.

(<u>1976 H-Grade Physics, Paper 2, Q2(a)</u>)

2. (*a*) A golfer hits a golf ball of mass $5{\cdot}0 \times 10^{-2}$ kg into the air. The club is in contact with the ball for $5{\cdot}0 \times 10^{-4}$ s. Calculate the resulting speed of the ball if the average force during contact is $3{\cdot}0 \times 10^{3}$ N.



If the pupil is familiar with the concept of impulse then he will know that he can calculate the final momentum of the ball in one step ($F \Delta t = m \Delta v$). The resulting speed of the ball is then equally easy to calculate.

If the concept of impulse has not been introduced, the pupil would have to calculate the average acceleration (using force = mass x acceleration) and then substitute this into an equation of motion ($v = u + at$) to calculate the resulting speed of the ball.

At least one College lecturer would not agree with us that impulse is a useful concept. He described it as "an 'impossible' concept which has largely disappeared from many syllabuses". He went on "I don't really know why it is named and given a special treatment. Students can be taught quite adequately in terms of 'force' without introducing confusing nomenclature like this". We suspect that many teachers, like this College lecturer, see no particular advantage to be gained by introducing the concept of impulse. It seemed to us all the more reasonable, therefore, to investigate the pupils' understanding of this concept. If our results indicate that the pupils are not understanding this concept, then we will have some justification for suggesting it should not be included in the syllabus. (It may be of interest to note that the revised H-Grade physics syllabus, to take effect in and after 1982, makes no specific mention of the concept of impulse but, at the same time, it does not say it has been deleted from the syllabus.)

The main part of investigation into the pupils' understanding of mechanics concepts, therefore, would involve a detailed examination of the following concepts:

<u>momentum</u>, <u>kinetic energy</u>, <u>(gravitational) potential energy</u>, <u>force</u> and <u>impulse</u>.

It would seem logical to include also the concept of '<u>weight</u>', which is closely related to gravitational potential energy, and is a specific example of the more general concept of force.

Having decided on the concepts to be investigated, we still had to decide what level of conceptual understanding we should be assessing. At this stage, we made a decision which has had a significant effect on our whole approach to the problem of assessing conceptual understanding. We decided that we would only concern ourselves with the formal 'scientific' meaning of these concepts, that is, their meanings as stated in a physics textbook.

To make this quite explicit, we consulted the three physics textbooks (89,90,91) most commonly used in Scottish schools in the teaching of the S.C.E. O-Grade and H-Grade Physics courses. We noted the following definitions of our selected concepts:

(1) Momentum is the product of mass x velocity
(2) Kinetic energy $E_k = \frac{1}{2} m v^2$ where m = mass, v = speed
(3) Gravitational potential energy E_p = mgh where m = mass, h = vertical height, g = gravitational field strength
(4) (Unbalanced) force F = mxa where m = mass, a = acceleration
(5) Weight W = mg where m = mass, g = gravitational field strength
(6) Impulse = $F \Delta t = m \Delta v$ = change of momentum

(Three points should be noted about these definitions:-

(a) None of the commonly used textbooks gives a symbol for momentum (or impulse). Reference to another authoritative source (92) gives the symbol as "p". Thus we may write "$p = mv$" and "$p = F \Delta t = m \Delta v$".

(b) In most cases, the definition is expressed as a symbolic equation (e.g. $E_k = \frac{1}{2} m v^2$). Although the exact meaning of the symbols is given, the pupil is encouraged to remember the symbolic equation.

(c) All the definitions are very formal and exact, and require 'formal' understanding of such concepts as 'mass' or 'gravitational field strength' before they can be meaningfully learned. The possibility that they will be learned by rote is quite high)

(2) Our decision to concentrate on the accepted 'scientific' meaning of these concepts had somewhat simplified the problem of deciding what factors about the pupil should be considered. We had effectively decided which pupils would be involved, since we could not expect pupils to have developed the 'scientific' meaning of a concept unless they had been taught it during their formal study of physics. Since there is only one syllabus in physics for all schools in Scotland, we can anticipate that the pupils will have been taught these concepts by O-Grade (S4), except for the concept of impulse, which will only be taught at H-Grade (S5). There is therefore little point in testing for the 'formal' understanding of the concepts much before the O-Grade stage (i.e. towards the end of S4).

Our investigation of conceptual understanding would be in no sense a longitudinal investigation of how the pupil's earlier intuitive understanding of the concept of force, for example, as 'push' or 'pull' gradually develops into the formal 'scientific' concept of force as stated in Newton's Laws of Motion. While we fully appreciated how valuable such information would be, both to the teacher and to those involved in designing the curriculum, we decided that our first priority should be the assessing of the pupil's formal understanding of the concepts at a certain stage of study. As we will later describe, we sampled the pupil's understanding at the O-Grade stage (S4), the H-Grade stage (S5) and the post-H-Grade stage (1st year College/University) and found some interesting variations in the level of understanding. In all cases, however, we were looking for evidence of understanding of the concepts in a formal, scientific sense.

In chapter 2, we noted that Lovell(32) had identified the particular concepts we were dealing with as 'second-order concepts at the third level of abstraction', and had concluded that the understanding of such concepts in the formal scientific sense would require that the pupil had reached the Piagetian stage of 'formal operational' thought. Throughout our investigation, we have tacitly accepted Lovell's conclusion, since it agrees with our own personal experience of teaching these concepts. We did not, however, accept the argument proposed by Shayer that such concepts can only be successfully taught to a minority of pupils, since only a minority of pupils will have reached the formal operational stage of cognitive development. We firmly believe that the pupils' understanding of such concepts is more dependent on such factors as a carefully graded teaching sequence, the quality of the learning experiences, and the interaction between teacher and pupil, than on the pupil having reached a particular stage of cognitive development. We can accept the idea of stages of cognitive development, and have applied it in our teaching by introducing a concept at the concrete operational stage and gradually progressing to the required formal operational level. We reject the idea, which is implied in much of Shayer's work, that we should wait until the pupils have reached the formal operational stage before we introduce the concept.

In our investigation of conceptual understanding, we are dealing with pupils who are likely to have progressed beyond the concrete operational stage of thinking. We are certainly requiring them to show evidence of formal operational thought when we test for the formal, 'scientific'understanding of the concepts. If we find evidence of some general lack of understanding at this formal level, we will not assume that this must imply that the majority of pupils have failed to reach a certain level of cognitive development. This would be, in our opinion, a very facile and unhelpful conclusion. A more constructive approach will be to examine critically the learning situation and to seek a possible explanation in terms of method of presentation, teaching sequence, information content and prior knowledge.

As we noted in chapter 2, the pupil's prior knowledge is an important factor in the learning of concepts. Gagne has suggested that the pupil's prior knowledge, in terms of prerequisite facts, concepts and principles, determines what further learning can occur. In Ausubel's view, the pupil's prior knowledge, in terms of its organisational structure as well as its content, determines whether meaningful learning can occur. In our investigation of the pupil's understanding of concepts, we will be concerned with the assessment of the pupil's prior knowledge - what he already knows - at a particular point in time. From our point of view, the pupil's prior knowledge and his present knowledge at the time of testing, are one and the same thing. We will be interested therefore in finding out what facts, concepts and principles the learner has stored in his long term memory and in looking for evidence of how they have been stored. In other words, we will be investigating some aspects of the pupil's cognitive structure.

Later in this chapter, we will discuss the methods by which we might hope to achieve this. At this stage, we would simply note that the learning theories described in chapter 2 stressed the importance of being able to assess the pupil's prior knowledge at any stage of learning. If we can devise a valid and reliable technique for assessing concept understanding towards the end of a course of study, then the same technique may be of some use to the teacher seeking to assess the pupil's prior knowledge at some intermediate stage of learning.

(3) We found that our decision to concentrate on the formal 'scientific' understanding of the concepts had also considerably simplified the problem of what was implied by the term 'understanding'.

For the purposes of our investigation, we shall assume that the term 'understanding' implies all of what Klausmeier (10) has described as the 'formal level' of concept understanding. This means that, in assessing 'understanding' of a concept, we will be interested in the pupil's ability to name the concept, to name its intrinsic or societally accepted defining attributes, to discriminate between examples and non-examples of the concept and to explain the basis of the discrimination in terms of the defining attributes. (We can recognise, in Klausmeier's description, some clues as to how we should test for understanding of a concept at the 'formal' level, and we will consider these in detail later in the chapter.)

In chapter 2, we mentioned that various researchers had found evidence to suggest that a pupil's understanding of the 'formal' concepts of physics, say, was often impeded by the intuitive, 'commonsense' preconceptions or misconceptions that the pupil had already incorporated into his cognitive structure. Ausubel (17) noted that "These preconceptions are amazingly tenacious and resistant to extinction". Leboutet-Barrell (7) noted that "there is some difficulty (for the teacher) in replacing the deeply engrained empirical notions by the newly acquired (scientific) ones". We can accept the possibility that such 'alternative frameworks' can often be more meaningful to the pupil than the ones he meets in the "rather strange, idealised world of physics in which all sorts of unstated simplifying assumptions tend to be made" (26). As we have stated, however, we will only accept the formal scientific meaning as evidence of the pupil's understanding. It would be, no doubt, of interest to follow up a pupil's idiosyncratic meaning of a concept to try to explain its origin, but, in the present investigation, we need not do this.

The problems involved in assessing a pupil's understanding of a concept can be considerably reduced, as we have described, by imposing certain delimiting conditions. The most important single condition would appear to be the level of understanding of the concept. We have decided to require the formal, 'scientific' level of understanding and, as a consequence, we have a clearer idea of what group of pupils will be involved and what sort of evidence we will look for in assessing understanding. We now consider how we might carry out the assessment.

Some methods of investigating concept understanding

In this section, we consider some existing methods of investigating concept understanding.

One of the most frequently used methods of investigation is problem-solving. The learner's problem-solving ability, it is argued, is a measure of his concept understanding. "The 'breadth' of a concept can be indicated by the relative complexity of relevant problems an individual can solve ..... Problem solving ability, if it were possible to devise an adequate examination, could be taken as an index of concept attainment" (93) 'Systematic problem solving' is one of the four cognitive ability groupings used in the S.C.E. O-Grade and H-Grade examinations. Stated explicitly (2), this ability is demonstrated when the candidate can:

(a) select a principle or principles in the form of a mathematical model

(b) select data, substitute numerical values and complete the calculation.

Candidates are always given due credit for being able to demonstrate their ability to select the correct principle even though they fail to complete the calculation correctly. Conversely, candidates are always given no marks at all if they select the wrong principle, even though they can complete the calculation correctly. (This is commonly called 'using wrong physics'). It is clear, therefore, that the emphasis in the problem solving ability is placed on choosing the correct principle.

If we attempt to investigate a pupil's understanding of a concept by requiring the pupil to solve a problem, we run into difficulties when the pupil fails to complete the calculation correctly but, at the same time, leaves some doubt as to which principle or principles he is applying.

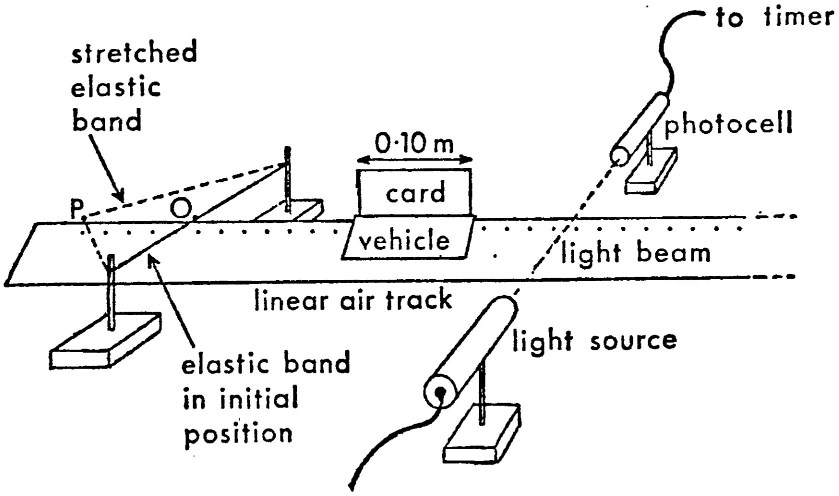
Larkin and Reif (80) have suggested that the learner should be told to "think aloud as much as possible" so that the problem solving process may be monitored, but this technique is only applicable in an interview situation. It could not be used in a group testing situation.

Since the emphasis in problem solving lies in choosing the appropriate principle, it seemed logical that we should concentrate attention on this aspect of the process. We might, for example, present the pupil with a number of problems to be solved, but in each problem, the pupil is only required to state the appropriate concept or principle which he would apply. He would not be required to actually perform any calculation, so the problem-solving process would not be clouded by arithmetical difficulties. The technique is most suited, perhaps, to problems which can be solved by applying a single principle. Many problems, however, involve the application of perhaps two or three principles <u>in a definite order</u>. This is considerably more difficult, since the pupil must now select a sequence of principles, and the relationship between the principles becomes very important, since each separate principle must be related to both the one which preceded it and the one which follows it.

We can illustrate this by the following example:
(We have chosen a problem from a S.C.E. H-Grade Paper II to ensure the difficulty level is appropriate)

(<u>1977 H-Grade Physics, Paper II, Q3(a)</u>)

3. A vehicle is travelling along a horizontal linear air track. A card on the vehicle passes through a light beam before the vehicle is stopped by a stretched elastic band. While the vehicle is being stopped, the centre of the elastic moves from O to P.



Results obtained from one run of the vehicle are:

Mass of vehicle and card = 1·1 kg
Length of card = 0·10 m
Time through light beam = 0·25 s
Stopping distance OP = 0·050 m

(*a*) Calculate
- (i) the average force exerted by the elastic band on the vehicle while it is being stopped;
- (ii) the time taken by the elastic band to stop the vehicle.

The complete solution to the above problem involves the following steps:

Part (i)

(1) Speed of vehicle on linear air track $= \dfrac{\text{length of card}}{\text{time through light beam}}$

$= \dfrac{0.10}{0.25} = 0.4 \text{ m s}^{-1}$

(2) Initial kinetic energy of vehicle $= \frac{1}{2}(\text{mass})(\text{velocity})^2$

$\frac{1}{2}(1.1)(0.4)^2 = 0.088\text{J}$

Final kinetic energy of vehicle $= 0$

(3) Work done by elastic in stopping vehicle $=$ loss in kinetic energy

$= 0.088\text{J}$

(4) Work done by elastic $=$ average force x stopping distance

Average force exerted by elastic $= \dfrac{0.088}{0.050} = 1.76\text{N}$

Part (ii)

(5) Initial momentum of vehicle $=$ mass x velocity

$= 1.1 \times 0.4 = 0.44 \text{ kg m s}^{-1}$

Final momentum of vehicle $= 0$

(6) Impulse of elastic on vehicle $=$ change in momentum of vehicle

$= 0.44 \text{ kg m s}^{-1}$

(7) Impulse = average foce x time for which force acts

Time taken to stop vehicle $= \dfrac{\text{Impulse}}{\text{average force}}$

$= \dfrac{0.44}{1.76} = 0.25\text{s}$

Steps (5), (6) and (7) could be replaced by steps (8) and (9)

(8) Average force on vehicle = mass x average acceleration

Average acceleration of vehicle $= \dfrac{1.76}{1.1} = 1.6 \text{ m s}^{-2}$

(9) Average acceleration $= \dfrac{\text{change in speed}}{\text{time taken}}$

Time taken to stop vehicle $= \dfrac{0.4}{1.6} = 0.25\text{s}$

The above analysis shows that the problem can involve as many as seven separate principles, which must be applied in a particular order.

It is clearly a very searching technique and may well be considered too sophisticated for pupils to be able to understand. However, as we will later describe, we have tried out this technique and we find that pupils can generally adapt to the technique without much difficulty.

Problems set in S.C.E. O-Grade and H-Grade extended-answer papers are generally 'structured' in the sense that the problem is presented as a sequence of steps, each step involving the application of a single principle. The pupil is 'led' through the problem, since each separate step follows from the previous steps. Sequencing a problem in this way avoids the problem of 'information overload' since the pupil is only required to process two, or perhaps three, bits of information at any one step.

Harke (94) has described an interesting technique, called the <u>randomised multiple-choice</u> format, which has been developed to facilitate the awarding of partial credit on machine-scoring of physics problems which involve several steps.

"The problem is stated conventionally, and it is suggested to the student to write out a solution to this problem in the space provided below the statement of the problem. Below this space are five or more multiple-choice items which correspond to steps in the correct written solution. These multiple-choice items have a random order and not the order in which the steps would occur in a written solution. This is to require the student to organise and use a sequence of physical and mathematical concepts similar to the sequence used in the solution of the same problem in free-response form ....

The student's score on the problem would be the number of multiple-choice items answered correctly which should correspond to the number of steps done correctly in the written solution."

Using a hierarchical analysis method, Harke was able to show that the students used the same or very similar cognitive process or problem solving skills in answering the multiple-choice items as they did in answering the free-response problems.

There is sometimes more than one method of solving a given problem. We can get some indication of a pupil's understanding of the concepts involved by noting which method he adopts. Consider, for example, the following problem:

"A ball of mass 0.1 kg is dropped from a height of 2m and rebounds to a height of 1.8m. Estimate the loss in kinetic energy of the ball on hitting the ground."

If the pupil solves this problem by simply calculating the loss in gravitational potential energy and equating this to the loss in kinetic energy on hitting the ground, then he has arguably a better understanding of the concepts involved than a pupil who uses the equations of motion to calculate the speed before and after hitting the ground, and then calculates, by the formula, the corresponding kinetic energies.

In the same way, the pupil who can immediately come up with the answer to the following problem is showing a clear understanding of the law of conservation of momentum.

"A space craft consists of one main section of mass M kg and three auxilliary units each of mass 0.1 M kg. During flight in a straight line in space, each auxilliary unit is jettisoned in turn by projecting it backwards from the main section so that it remains motionless in space. After all three auxilliary units have been jettisoned, the speed of the main section is 13m s^{-1}. Determine the speed of the space craft before the first auxiliarry unit is jettisoned."

The ability to solve problems is, of course, the ultimate test of concept understanding. There is also a need to test the pupil's understanding of the concept at intermediate stages of development of the concept. Some other technique would be required for such intermediate testing of concept development.

Multiple-choice items can be used to test for recall of basic concept definitions, or to test the ability to apply a principle, as the following examples show:

1977 O-Grade Paper II Q7.

Which of the following measures force?

A mass x acceleration
B mass x velocity
C $\frac{1}{2}$ x mass x velocity^2
D weight x height raised
E mass x heigh raised

1975 H-Grade Paper I Q9

An unbalanced force of 60N acts on a mass of 3.0 kg. If the force acts for 0.1s, the impulse given to the mass is

A 20 Ns kg^{-1}
B 60 Ns
C 18 kg Ns
D 20 N kg^{-1}
E 60 N

However, as was discussed in chapter 4, the results of multiple-choice tests require careful detailed analysis before the teacher can obtain specific information about a pupil's understanding of a concept. In general, teachers cannot afford to spend a great deal of time analysing the results obtained from a multiple-choice test. In most cases, they must be satisfied with a total score for each pupil. A great deal of potentially useful, diagnostic information is wasted because the teacher cannot afford the time to analyse the results in full.

Computer programs are available to perform the detailed item analysis of a multiple-choice test. One such program was used to analyse the pupil tests described in chapter 4. More recently, multiple-choice test analysis programs have been developed for in-school use on a desk-top microcomputer. The pupil would record his responses on a mark-sense card, which he would then feed into a card reader connected directly to the microcomputer. In a very short time, the computer would print out a detailed analysis of his performance, showing not just the pupil's total score, but his score on each separate 'sub-test'. A sub-test is a selection of items from the whole test battery, which have been grouped together (by the teacher) because they relate to a specific concept or principle. If desired, the pupil's actual score on any sub-test could be compared to an 'expected score' (a hypothetical score based on the item statistics accumulated by the computer) and, where the pupil failed to reach the expected score, he would be directed to some remedial teaching sequence. The computer would provide the teacher with various summary reports showing, for example, the distribution of pupil total scores and scores on each sub-test for a whole class, the detailed item statistics for a particular test, and the cumulative profile of performance for any selected pupil over a number of tests.

A computer program of the type just described can provide the teacher with comprehensive diagnostic information about the level of understanding of each individual pupil. A crucial factor, however, will be the quality of the test items used. Clearly there will be little value in having detailed information about pupil performance on a multiple-choice test in which the items were inappropriate, invalid and/or unreliable. A great deal, therefore, will depend on the construction of the initial test.

In the past, multiple-choice tests have been norm-referenced tests. For our present purposes, a criterion-referenced test is more appropriate. Pilliner (95) has given a useful summary of the differences between norm-referenced and criterion-referenced tests, as follows:

"First, they differ in the purpose for which the tests were constructed: for the norm-referenced test, to place the pupil at a point on a continuum determined by his test performance in relation to that of other pupils; for the criterion-referenced test, to place him in a quite different continuum defined by a set of progressive tasks at a point which marks off the tasks he can do from those he cannot yet do.

Second (following from the first), they differ in the manner in which they are constructed: for the norm-referenced test, a construction procedure directed at producing an instrument capable of discriminating as widely as possible among the pupils tests, from which follows the rejection of items which do not aid this discrimination; for the criterion-referenced test, inclusion of items representing a continuum of relevant tasks which may or may not include items the norm-referenced test constructor would reject.

Third, they differ in the use to which the information derived from the administration of the test is put. The norm-referenced test aids selection .... (and) helps predict subsequent success. The criterion-referenced test pinpoints for the teacher the problems encountered by pupils and, more generally, provides information about what each pupil can or cannot do."

For each pupil, the norm-referenced test will produce a single total score, whereas the criterion-referenced test will produce more specific information about pupil performance in the form of a 'profile' of part-scores.

A criterion-referenced test is designed to measure the pupil's performance or attainment in terms of some previously specified criterion performance. Before the test can be constructed, the desired intellectual skill is analysed into its component parts. This analysis should take account of the particular aim of the teaching sequence, the logical structure of the content-matter concerned, and the prior knowledge of the pupils. The outcome of the analysis will be a series of specific (behavioural) objectives, on the basis of which the items for the test may be selected. The items which are included in the test must be, individually, valid measures of some aspect of the required criterion or 'domain of behaviour' and, collectively, must provide an adequate random sample of the 'domain'.

Pilliner (95) has pointed out some of the problems involved in constructing criterion-referenced (or 'domain-referenced') tests. These include the detailed mapping of a large domain, the production of a test which is an unbiased sample of a large domain but still of practicable length, the fixing of 'cut-off' scores and the reliability and validity of the final test. The construction of criterion-referenced tests and the technology of domain-referenced testing are described in detail by Brown (85).

A major advantage of the criterion-referenced test is that it provides the teacher with diagnostic information about each pupil's performance. As Brown puts it "it has the potential to be used to aid pupils' learning". Criterion-referenced tests, therefore, are of particular value in the formative assessment of pupils' abilities at each stage of the learning sequence. For example, if the teacher was about to introduce a new concept or principle to a class, it would be helpful if the teacher could be certain that all the pupils had the necessary prior knowledge and were therefore 'ready' to learn the new concept. In the same way, both the teacher and pupil would benefit from diagnostic information about the growth of understanding of the concept as the learning sequence progressed. Where the pupil shows a lack of understanding, it would be helpful if the possible cause could quickly be ascertained.

There is, we believe, a place for criterion-referenced multiple-choice tests of concepts and principles which could be used by the teacher in the classroom to obtain diagnostic information on the pupils' understanding of a particular concept or principle. Existing multiple-choice items taken from past S.C.E. papers or other sources, are not suitable for the purpose we have in mind, since they generally involve more than one concept or principle and, being norm-referenced, they will be highly discriminating. The sort of test items we have in mind would be specifically related to individual concepts (at least to start with) and would give objective evidence of the pupil's increasing 'mastery' of the concept, as learning progressed.

Ultimately, we would envisage the teachers being able to select appropriate test items to suit the requirements of their particular classes from a large 'item bank' of criterion referenced test items. This would involve the use of some form of 'item specification' code to aid selection of appropriate items. However, this is not our immediate concern. We must first consider the basic specifications for the proposed test of concept attainment. These test specifications would in practice, be applicable to our investigation of the pupils' concept understanding.

Some practical and theoretical considerations

For our purposes, we required to test the conceptual understanding of a large, representative sample of pupils, at O-Grade stage and beyond, using a standardised testing procedure. This, we realised from the outset, would not easily be achieved by a clinical interview technique, in view of the number of pupils likely to be involved. The individual interview has certain advantages (e.g. it allows the interviewer to follow up certain answers to gain more information about the pupil's understanding, and it allows the pupil to ask questions where necessary) but it is slow and cumbersome in use, and is difficult to maintain a standard format for all interviews. There would also be practical difficulties in carrying out such individual interviews in a school situation over an extended period of time. We decided that the most appropriate technique, to obtain as much information as possible in the time available, would be large scale group testing supplemented, where possible, by individual interviews to check the validity and reliability of the data. The test materials would therefore have to be in a form suitable for use with a large group of pupils, probably in a classroom situation, and preferably with the active co-operation of the teacher.

If we hoped to enlist the active co-operation of the teachers in administering our test material, then it was clear that the material would have to fulfil certain basic requirements.

(1) The 'content-validity' of the test material would have to satisfy the teachers as subject matter experts. This would require, for example, that the material would have to be clearly appropriate to the S.C.E. physics syllabus, and that the language, symbols and units used were in accordance with standard practice.

(2) The test material would have to be in a format which was easy to administer to a group of pupils. This would probably involve a pencil-and-paper test with clear unambiguous instructions.

(3) The test material should be attractively presented, and should be interesting and challenging to the pupil. The teachers must be convinced that the completion of the test is likely to benefit the pupil in some way.

(4) The time required to complete the test should be reasonable. This would probably be 30-40 minutes as a maximum.

If we are considering the possible specifications of a concept attainment test for use by the teacher in the classroom, then the time required must be much less than 30 minutes - in this case 5-10 minutes would be more reasonable. For such tests, we would add two further conditions to the above list:

(5) The test would have to be easily and meaningfully interpreted by both teacher and pupils. This would probably involve a coded response format with a marking key. Particular patterns of response should be anticipated and appropriate 'error messages' should be provided.

(6) The test format should be such that the teacher can feel reasonably confident in his ability to adapt the format to test conceptual understanding in other areas of the syllabus. In other words, the test format should be usable in a wide variety of different contexts.

From theoretical considerations, if a pupil has fully grasped a concept, we might expect him to be able to :

(1) name the concept
(2) identify instances of the concept
(3) discriminate between examples and non-examples of the concept
(4) state the rule(s) which he is applying to discriminate between instances and non-instances
(5) solve problems involving the concept

If a pupil has fully grasped a principle, we might expect him to be able to use the principle to

(1) predict the consequences of a given set of conditions
(2) infer the initial conditions which produces a given outcome
(3) explain why a given outcome must follow from a given set of conditions
(4) solve problems

If we are investigating the pupil's understanding of a concept or principle, then we should require him to demonstrate any or all of these abilities.

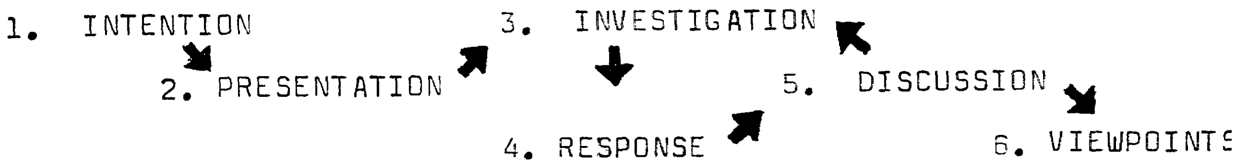
What techniques are available to do this? We have already discussed a possible technique, based on the conventional extended answer problem, which might be appropriate for investigating concept understanding in a problem-solving situation. For more basic levels of understanding, we might use multiple-choice test items, but most existing items, as we have noted, will be highly discriminating norm-referenced items and may therefore be inappropriate. Criterion-referenced multiple-choice items are not yet available in quantity.

The word-association technique, described in chapter 2, is more suited to investigating the inter-relationships between concepts, and would not provide much information about the pupil's ability to discriminate between instances and non-instances, or to use a principle for inference or prediction. In addition, it is difficult to see how teachers could get rapid feedback of information from the word-association technique.

None of the available techniques require the pupil to discriminate between examples and non-examples of a concept or principle, yet, as Klausmeier (10) and Markle and Tiemann (11) have pointed out, this must be an essential ingredient of any test of concept attainment. We decided, therefore, to try to devise a simple objective method of doing this.

A method of testing 'concept discrimination'

We were interested to read of a programmed learning technique called <u>structural communication</u> (82,83,84) since the assessment component of this technique seemed to be appropriate to our purposes. Egan has described how the technique would operate.



"The basic element of Structural Communication is a 'Study Unit' .... Following the PRESENTATION (a specially prepared test) the student comes to the INVESTIGATION section, where he is faced with three to five problems, each covering a major theme of the material of the PRESENTATION. The student makes his RESPONSE by means of a matrix of approximately 20 items, which re-express in summarised or 'structured' form the content of the presentation ... Each problem is answered from the same matrix and the knowledge elements are 'structured' in such a way that, as the student builds his response, the various patterns and relationships of meaning emerge. .... In effect, each problem presents the student with a different organising principle and, while he is engaged in re-assessing the items and relationships according to the different principles, he is performing a by no means trivial synthetic intellectual act .... The authors can assess in advance the implications of certain omissions, combinations, patterns or particular inclusions in a student's response, and so offer a variety of DISCUSSION comments to refine, correct, reinforce or simply discuss the response made"

The part which particularly interested us was the use of the same 'response indicator' to answer a number of problems. In a problem solving situation, such as we described earlier (p.138), each box in the matrix would contain a principle (e.g. <u>force</u> = <u>mass</u> x <u>acceleration</u>)

The pupil would choose the appropriate sequence of boxes to indicate what principles he would apply to the problem and their sequence of application.

We then extended the idea a stage further. Suppose each box in the matrix contained an instance or non-instance of a particular concept. The pupil could then be asked to categorise each box as an instance or non-instance of the concept. Clearly the same box could function as an instance of one concept, but a non-instance of another concept. By suitable selection of instances, we could require the pupil to make quite fine discriminations and so get an indication of the level of understanding of the concept.

Johnstone and Mughol (96) described a somewhat similar response chart which they developed for a group diagnostic test of the concept of '<u>resistance</u>'. Gilbert and Osborne (26,27) have, more recently, described their '<u>interview-about-instances</u>'technique for investigating concept understanding. They used a set of simple line drawings on individual cards to represent the instances to be discussed in an individual interview situation. They have used the method to investigate the concepts of '<u>work</u>' and '<u>electric current</u>' over a wide age range (7-18) and claim that "asking students to classify instances appears to be more pertinent and penetrating than asking for a definition".

Gilbert and Osborne note "the problem of choosing a limited but adequate set of instances so that various aspects of a student's understanding of a concept can be explored" and "the problem of choosing the order of the instances in that a particular instance may influence a student's response to a later instance". They used some ten to twenty separate instances. We used, in our investigation, a 5 x 5 grid of boxes. Presenting the instances as a 5 x 5 array makes the order of presentation less critical, since all 25 instances are displayed all the time, and the pupil can consider them in any order (though it appeared that they generally considered them in numerical order).

It may be argued that presenting all 25 instances at the same time would lead to 'information overload'. In fact this does not occur, since each instance is considered separately. The pupils were instructed to consider one concept, and to go through the given set of instances, recording only those which were examples of that concept, then to repeat the process for each of the remaining concepts in turn. (It was interesting to note that teachers adopted a quite different strategy. They considered each instance in turn and categorised it as an example of one or more concepts).

At this stage, we were still not fully satisfied that we were testing the pupil's understanding of the concept. In terms of Bloom's taxonomy (87), it seemed that we had progressed from knowledge through comprehension and application and were on the fringes of analysis, but we had not dealt with synthesis or evaluation. To use another analogy, we were, up till now, 'filing' data under different concept headings, and this certainly requires a degree of 'understanding' of the data, but using our 'filing system' efficiently to extract all the relevant data may require a greater degree of 'understanding'. We decided, therefore, to start again from the other end, as it were.

We now introduced what later became known as "the dreaded quantity X". We assumed a given quantity could be identified by a series of 'clues', each 'clue' being a little more specific than the previous one. For example, suppose the first 'clue' was "The quantity X is proportional to the mass of a body". We argued that a pupil would be able, from his understanding of the different concepts, to suggest several possible concepts which would fit this 'clue'. For example, momentum, kinetic energy, weight and density would be valid answers -

but not force or impulse. We further argued that, given a second 'clue' (e.g. "The quantity X is conserved in an elastic collision"), the pupil would narrow down his possible answers by using the combined information provided by the two clues. And if we provided a third, and a fourth 'clue', his choice of concept would be narrowed down more and more until only one concept remained. Any further clues should only serve to confirm the correctness of this choice.

The number of valid concepts identified at each step would, we argued, be a measure of the pupil's concept understanding. Valuable information would also be derived from invalid concepts suggested by the pupil at any stage.

We would suggest that the thought process involved in this technique is <u>evaluation</u> of each new piece of information against the existing information provided by the previous 'clues'. From only the first, very general, 'clue' the pupil has to <u>synthesise</u> a set of valid responses. As each new 'clue' is provided, he will have to <u>discriminate</u> between these responses in the light of the available information, and discard any responses which are no longer valid. This will require a careful <u>analysis</u> of the properties of each concept.

The technique was then further refined by asking the pupil "How confident are you that you have correctly identified the quantity X?" He was asked to respond to this question on a five-point scale varying from (1): "I have no real idea, so I have just made a guess" to (5): "I know it is ...... and I can prove it". We would expect a 'normal' pattern of responses to show a gradual increase in the 'confidence rating', as the pupil narrows down the number of possible concepts involved.

A much more interesting situation arises when a sharp drop is recorded in the 'confidence rating'. When such an abrupt change occurs, we would infer that, for that pupil, the latest piece of information conflicts, in some way, with the existing information and cannot be meaningfully assimilated.

In some situations, the pupil will ignore the new information and retain his previous choice of concept, but he will now be less confident, knowing that he has not used all the given information. In other situations, he will abandon his previous choice of concept because the new information is clearly incompatible with his chosen concept. If the new information is specific enough, he may choose a concept to fit only the new information, and ignore the existing information. If the new information is non-specific, he may simply guess. In either case, he is certainly less confident.

A brief description of the test material

We conclude this chapter with a brief description of the test material as used in the 1979-80 trial. A more detailed description, together with an explanation of the experimental procedure adopted and an analysis of the results obtained, will be given in the next chapter.

The test material was made up of two parts, 1 and 2.

In part 1, the pupil was given a series of nine statements, one per page, about a quantity X. After each statement, the pupil was asked to write down what he thought the quantity X could be, and to indicate how confident he was that he had correctly identified the quantity X by ticking one of five boxes. The quantity X was at no time formally identified.

A copy of the pupil instructions for part 1, and two sample pages from part 1, are given in Table 18.

In part 2, the pupil was provided with a chart containing 25 numbered boxes. Each box contained some information about one (or more) of the concepts momentum, kinetic energy, gravitational potential energy, force or impulse. The pupil was instructed to consider each concept in turn, and to write down, on a prepared record sheet, the numbers of the boxes on the chart which contained some information about that concept. The pupil was finally asked to select, for each concept, the three most important features from the ones given in the chart.

A copy of part 2 is given in Table 19

A sample of the whole test, as completed by an H-Grade pupil is given in Appendix G.

TABLE 18 Sample of part 1 of test material

INSTRUCTIONS FOR PART 1.

1. We are trying to find out how quickly you can identify a particular physical quantity X (eg mass, velocity, temperature, resistance, etc.) from a series of related statements, all of which apply to the quantity X. We are also interested in how confident you are about your answers.

2. On the next page you will find the first statement about the quantity X. When you have read this statement, we want you to write down the NAME of a physical quantity the statement applies to. If you think the statement can refer to more than one quantity, you should write down the names of ALL these quantities.

   After writing down your answer, put a tick in one of the five boxes to indicate how confident you are about your answer. (For the first one or two statements, you may be GUESSING what the quantity X is, but as you read more statements about the quantity X, you will sooner or later reach a stage when you KNOW what the quantity X is).

3. On each of the following pages, another statement about the quantity X is added. We want you to write down what you think quantity X could be, and to indicate how confident you are about your answer, at each successive stage, even when you feel sure you know what the quantity X is.

4. Be sure your answers are written down BEFORE you read the statements on a later page. Do NOT go back to change or add to an answer on a previous page.

5. Before you start, please complete the following:-

NAME ______________________ MALE ☐ /FEMALE ☐ AGE ☐

SCHOOL/COLLEGE ______________________________

STAGE OF STUDY: O-Grade ☐ H-Grade ☐ HND ☐ B.Sc ☐

TABLE 18 continued

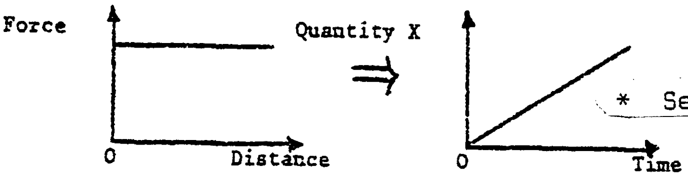
WHAT IS THE QUANTITY X?

1. "The quantity X is proportional to the mass of a body".

2. "The quantity X is possessed by moving bodies".

3. "The quantity X is conserved in elastic collisions between bodies".

4. "The quantity X increases when a force is applied to a body, as indicated below:-



* See footnote on page 183

Write down what you think the quantity X is.

How confident are you that you have correctly identified the quantity X? (Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be......	
I think it is......., but I would like more information	
I am sure it must be......	
I know it is.....and I can prove it	

NOW GO ON TO THE NEXT PAGE

TABLE 18 continued

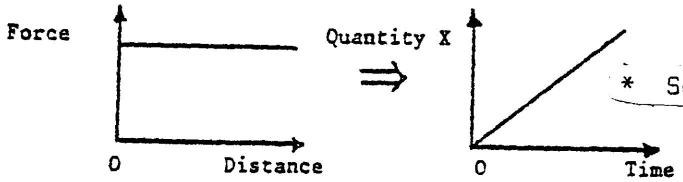
WHAT IS QUANTITY X?

1. "The quantity X is proportional to the mass of a body".

2. "The quantity X is possessed by moving bodies".

3. "The quantity X is conserved in elastic collisions between bodies".

4. "The quantity X increases when a force is applied to a body, as indicated below:-



* See footnote on page 183

5. "The change produced in the quantity X is a measure of the work done by the applied force."*

6. "When a body is released from a height above the ground, the quantity X increases as the body falls."

7. "The quantity X is a scalar quantity".

8. "The quantity X is measured in J".

9. "The quantity X is defined by the equation $E_k = \frac{1}{2}mv^2$."

Write down what you think the quantity X is.

How confident are you that you have correctly identified the quantity X? (Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be......	
I think it is....., but I would like more information	
I am sure it must be.........	
I know it is.......and I can prove it	

NOW GO ON TO THE NEXT PAGE

TABLE 19 Sample of part 2 of test material

INSTRUCTIONS FOR PART 2.

1. We are interested here in how much you can tell us about five related quantities in mechanics - MOMENTUM, KINETIC ENERGY, GRAVITATIONAL POTENTIAL ENERGY, FORCE and IMPULSE.

2. We have provided you with a CHART to help you. Take out this chart and look at it. You will see that there are 25 numbered boxes on the chart. Each box contains ONE piece of information - a statement, a formula, a diagram - about one or more of the five quantities mentioned above.

3. Take each of the five quantities in turn, starting with MOMENTUM. Using the chart, write down, in the spaces provided overleaf, the NUMBERS of all the boxes on the chart which you think contain some information about momentum. Then do the same for each of the remaining quantities.

   Thus, if you were considering the quantity 'FORCE", you might decide that box 6 on the chart contains some information about 'force' and you would therefore write the figure '6' in one of the spaces under the heading <u>FORCE</u> (See overleaf)

   There are 12 spaces provided for each of the five quantities. You do NOT have to put numbers in ALL 12 SPACES. Put in only as many as you think are appropriate.

   You can enter some numbers under more than one heading.

   You need not use every number on the chart.

4. Once you have entered all the numbers for a particular quantity, look carefully on the chart at the boxes to which these numbers refer. Select the THREE numbers which, in your opinion, identify the MOST IMPORTANT features of the particular quantity being considered. Enter these three numbers, in ORDER OF IMPORTANCE, in the '1', '2' and '3' spaces at the end of the row.

TABLE 19 continued

For each physical quantity, fill in the NUMBERS of all the boxes on the chart which refer to that quantity.

MOMENTUM

													1	2	3
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐

KINETIC ENERGY

													1	2	3
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐

GRAVITATIONAL POTENTIAL ENERGY

													1	2	3
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐

FORCE

													1	2	3
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐

IMPULSE

													1	2	3
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐

Now complete the following:-

"As far as you were concerned, did the chart provided include ALL the important features of EACH of the physical quantities?"

YES ☐ NO ☐

If you answered NO, please indicate what important feature(s) were omitted from the chart:-

____

____

____

____

____

____

TABLE 19 continued

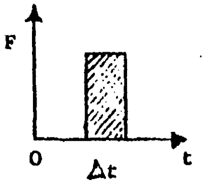
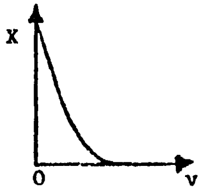
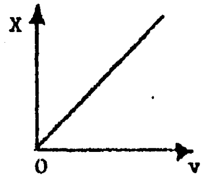
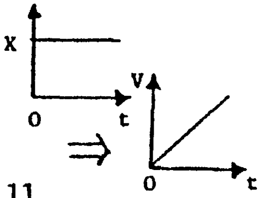
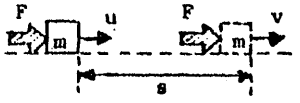
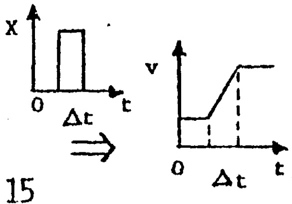
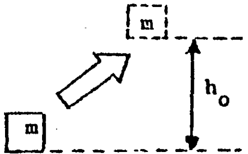
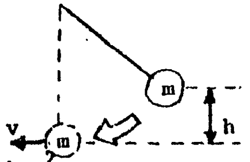
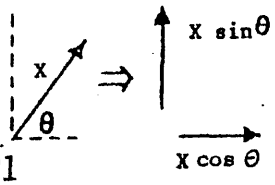
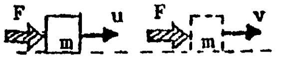
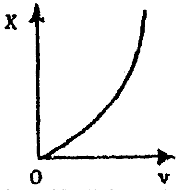
 1	$E_k = ½mv^2$ 2	Measured in N 3	 4	Conserved ONLY in elastic collisions 5
$F = ma$ 6	A scalar quantity 7	 8	Measured in J 9	$E_p = mgh$ 10
 11	$F = \frac{d(mv)}{dt}$ 12	 $Fs = ½mv^2 - ½mu^2$ 13	Increased in an explosive collision 14	 15
$p = mv$ 16	 $\Delta E_p = mgh_o$ 17	Conserved in ALL collisions 18	 $½mv^2 = mgh$ 19	Measured in Ns 20
 21	 $Ft = mv - mu$ 22	 23	$F = m \frac{dv}{dt}$ 24	Decreased in an inelastic collision 25

CHART FOR PART 2

CHAPTER 6 - THE 1979-80 FIELD TRIAL

Introduction

At the end of the previous chapter, we gave a brief description of the trial material used in the 1979-80 field trial. We will give a more detailed description of the test material in this chapter. We will also describe how the field trial was carried out and give an analysis of the results obtained. Finally we will explain the revisions which were carried out before the 1980-81 field trial.

A more detailed description of the test material

We start by considering part 1 of the test material.

It will be recalled that, in this part, the pupil was given a sequence of nine statements about the quantity X. The sequence started with a very general statement (e.g. "The quantity X is proportional to the mass of a body") and gradually became more and more specific. The final statement was the definition of the quantity X (e.g. "The quantity X is defined by the equation $p = mv$ ") The sequence of nine statements for the concept of momentum is given in Table 20 (overleaf)

TABLE 20 - List of nine statements for 'momentum'

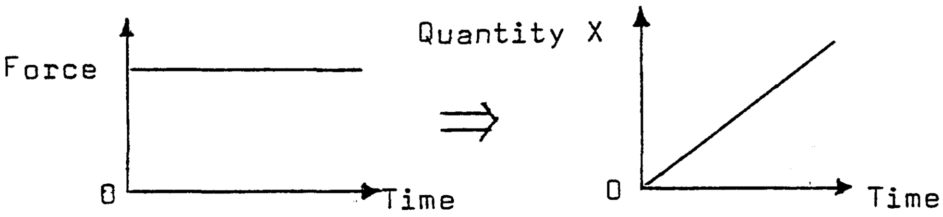
(1) The quantity X is proportional to the mass of a body.

(2) The quantity X is possessed by moving bodies.

(3) The quantity X is conserved in elastic collisions between bodies.

(4) The quantity X can be resolved into components.

(5) The quantity X increases when a force is applied to a body as indicated below:-



(6) The change produced in the quantity X is a measure of the impulse of the applied force.

(7) The quantity X is a vector quantity.

(8) The quantity X is measured in kgm s^{-1}.

(9) The quantity X is defined by the equation $p = mv$.

There were, in all, six concepts being tested (i.e. momentum, kinetic energy, gravitational potential energy, weight, force and impulse.) For each concept, a sequence of nine statements was prepared. These statements were carefully matched, so that the same statement (or the same form of statement) appeared at about the same position in each sequence.

For example, statement 1 for momentum, kinetic energy, gravitational potential energy and weight was "The quantity X is proportional to the mass of a body". This statement does not apply in the case of force and impulse, so an alternative statement "The quantity X is related to the mass of a body" was used. (It can be argued that this statement is equally inapplicable, in the sense that it is the effect of the force (or impulse) which is related to the mass of the body. The results indicated, however, that the alternative statement was apparently acceptable to the pupils)

Statement 7 on each list of statements was either "The quantity X is a vector quantity" or "The quantity X is a scalar quantity" as appropriate to the concept involved. Statement 8 on each list gave the units of the quantity X, while statement 9 gave the defining equation. One statement in each list gave the information in a graphical form.

Table 21 summarises the list of statements for each concept.

Table 21 - Summary of statements about the quantity X

		p	E_k	E_p	W	F	p
1a	Proportional to mass	*	*	*	*		
b	Related to mass					*	*
2	Possessed by moving bodes	*	*	*	*		
3a	Conserved in elastic collisions	*	*				
b	Involved in both elastic/inelastic collisions					*	*
4a	Can be resolved into components	*			*	*	*
b	Horizontal component always zero				*		
5	Causes a change in velocity				*	*	*
6	Diagram showing relationship to force/time or force/distance graph	*	*	*	*	*	*
7	Change produced in X is a measure of	*	*	*		*	*
8	Depends on position of body			*			
9	For freely falling body, X increases/decreases during fall		*	*			
10	Vector/scalar quantity	*	*	*	*	*	*
11	Measured in	*	*	*	*	*	*
12	Defining equation	*	*	*	*	*	*

At first glance, some of the statements may not appear to apply to the stated concept. For example, it may not be immediately obvious that moving bodies should possess either gravitational potential energy or weight. The lists of statements for each concept were, however, vetted by a number of experienced teachers/lecturers in physics and it was agreed that, with the exception of statement 1 for force/impulse referred to above, the suggested statements could apply to each concept, although some were rather unusual. It was suggested that statement 2 for gravitational potential energy and weight might be changed to "The quantity X is possessed by falling bodies", to make it more obvious which concept was involved. It was agreed, however, that the given statement was not incorrect.

Appendix H shows, for each of the six concepts involved, the complete list of nine statements. Statement 1 for force/impulse was left unchanged, for want of a better alternative.

For each list of nine statements, there is a minimum number of statements required to identify the concept. This is shown in Table 22.

Table 22 - Minimum number of statements to identify the concept

Concept	Minimum number of statements required
Momentum	5
Kinetic energy	4
Potential energy	4
Weight	4
Force	6
Impulse	5

The nine statements appeared on nine consecutive pages of the test booklet. On each page, there also appeared a 'confidence rating' table, as shown below

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be	
I think it is ...... but I would like more information	
I am sure it must be	
I know it is ...... and I can prove it	

To avoid the pupil having to refer back to a previous page for information, the statements were repeated on each successive page, one further statement being added to the list on each page.

There are more than four valid responses to the statement "The quantity X is proportional to the mass of the body". For example, in addition to momentum, kinetic energy, gravitational potential energy and weight, there are such concepts as density, angular momentum, moment of inertia and centripetal force. If the pupils already had been asked to consider certain concepts (as in part 2) then these concepts would, no doubt, be more likely to be given as possible responses. For this reason, we chose to put this part of the test first, so that the pupils' responses would not be influenced by what they were asked to do in the other part of the test. (In the 1980-81 trial the order was reversed, and there was some evidence that the concepts that were considered in one part of the test did influence the responses in the other part of the test). For the same reason, we concluded that each pupil could be given only one set of nine statements to work through. The pupils' responses to a second set of statements, we argued, were likely to be coloured by his previous responses.

As we noted earlier, there is a minimum number of statements required to positively identify each of the given concepts. If the pupil was presented with a complete list of nine statements for a given concept, we could quite reasonably ask the pupil to indicate the number of statements he required to positively identify the concept. For example, suppose the concept was weight, for which four statements are required for positive identification. If a pupil claims he identifies the concept from, say, the first two statements only, then we may infer he has not considered all the possibilities. Conversely, if he claims he needed, say, eight statements to identify the concept, then clearly he has not processed the information effectively. In either case, we can infer a lower level of concept understanding than that of a pupil who identified the concept using the minimum required number of statements.

In each test booklet, page 1 was taken up with instructions on how to complete part 1. The instructions were the same in all cases. The remaining nine pages (2-10 inclusive) were used to present the nine statements about one concept. Page 11 of the booklet had a complete list of nine statements for another of the six concepts being tested, and the pupil was asked to indicate the statement by which he identified the concept.

The test booklets were assembled as follows:-

(i) 75 copies of pages 1-10 for, say, the concept of momentum were collated.

(ii) Of these 75 copies, 15 copies had the list of nine statements for 'kinetic energy' as page 11, 15 have the list for 'force' as page 11, and so on.

(iii) Similar sets of 75 copies for the other five concepts were produced.

In this way each list of statements appeared in 150 copies of the test booklet. In 75 copies, it is presented as pages 1-10, and in 75 copies as page 11.

Part 2 of the test material was the same in all copies of the test booklet. A copy of part 2 was given in Table 19.

In part 2 of the test material, the pupil was provided with a chart showing a 5 x 5 grid of numbered boxes, as in Figure 7. Each box contained some information which applied to one, or more, of the five chosen concepts. The information in some boxes was a statement of words (e.g. 'Decreased in an inelastic collision'); in other boxes it was an equation (e.g. '$E_k = \frac{1}{2} mv^2$') Some boxes contained diagrams, while other boxes contained graphs of a quantity 'X' against time (t) or velocity (v).

Figure 7 - 5 x 5 grid of numbered boxes used in Part 2

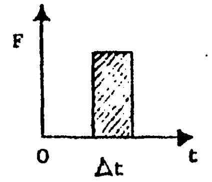
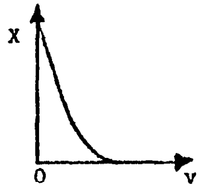
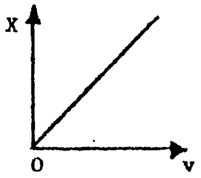
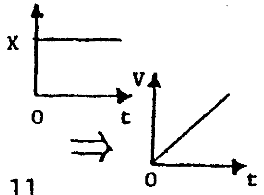
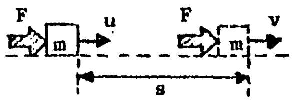
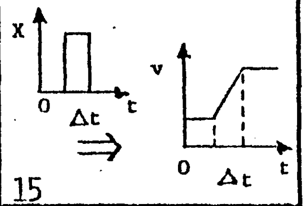
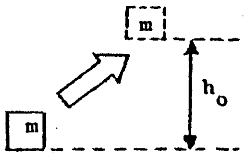
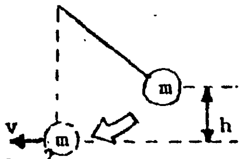
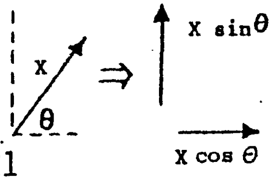
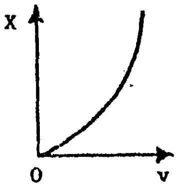
 1	$E_k = \frac{1}{2}mv^2$ 2	Measured in N 3	 4	Conserved ONLY in elastic collisions 5
$F = ma$ 6	A scalar quantity 7	 8	Measured in J 9	$E_p = mgh$ 10
 11	$F = \frac{d(mv)}{dt}$ 12	 $Fs = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ 13	Increased in an explosive collision 14	 15
$p = mv$ 16	 $\Delta E_p = mgh_o$ 17	Conserved in ALL collisions 18	 $\frac{1}{2}mv^2 = mgh$ 19	Measured in Ns 20
 21	 $Ft = mv - mu$ 22	 23	$F = m\frac{dv}{dt}$ 24	Decreased in an inelastic collision 25

CHART FOR PART 2

One group of boxes on the chart contained the defining equations for the chosen concepts, viz.

$E_k = \frac{1}{2}mv^2$

2

kinetic energy

$E_p = mgh$

10

gravitational potential energy

$F = ma$

6

force

$p = mv$

16

momentum

A second group of boxes related to the units of the chosen concepts, viz

Measured in N

3

force

Measured in J

9

kinetic energy and/or gravitational potential energy

Measured in Ns

20

impulse (and/or momentum)

The unit "kg m s^{-1}" for momentum did not appear on the chart. The "Ns" is dimensionally equivalent to the "kg m s^{-1}"

Another group of boxes related to collisions, viz.

Conserved ONLY in elastic collisions

5

<u>kinetic energy</u>

Conserved in ALL collisions

18

<u>momentum</u>

Increased in an explosive collision

14

<u>kinetic energy</u>

Decreased in an inelastic collision

25

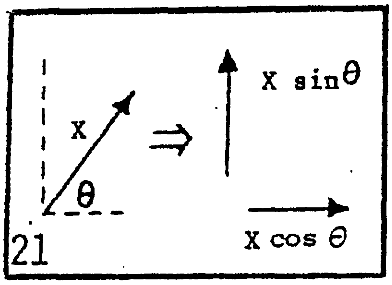
<u>kinetic energy</u>

One box referred directly to a scalar quantity, but there was no corresponding reference to a vector quantity. Instead, a diagram showing a (vector) quantity being resolved into components was provided.

A scalar quantity

7

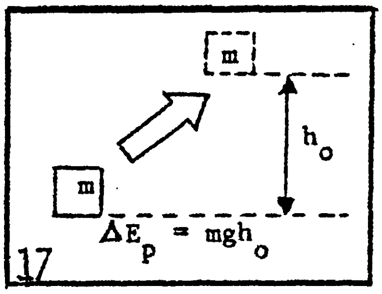
<u>kinetic energy and/or</u>
<u>gravitational potential energy</u>



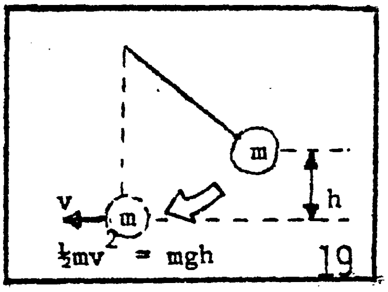
21

<u>momentum</u>, <u>force</u> and/or
<u>impulse</u>

Two boxes referred to energy changes, viz.

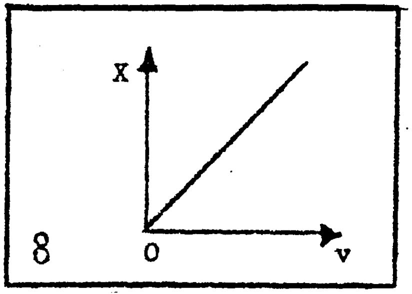


gravitational potential energy

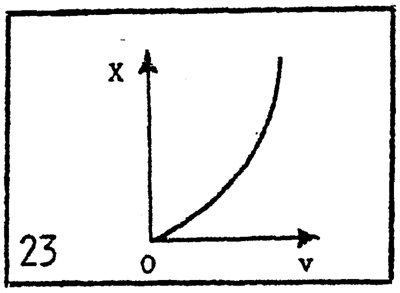


kinetic energy and/or gravitational potential energy

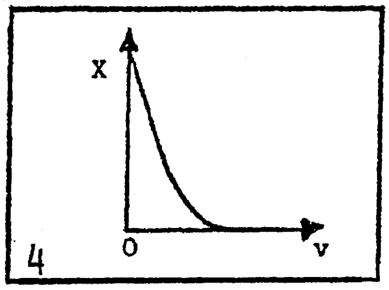
A group of three boxes showed the graph of the quantity X plotted against the velocity v



momentum

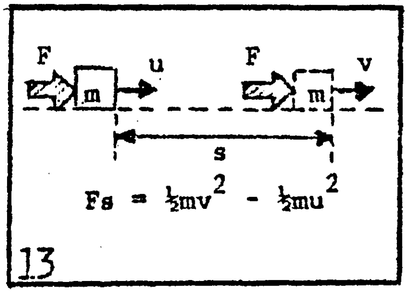


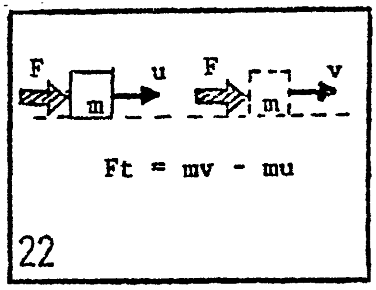
kinetic energy



(This graph was meant to show gravitational potential energy, but the curvature is, of course, wrong. We can offer no excuses for this careless error)

Two boxes had a similar diagram, but referred to quite different concepts

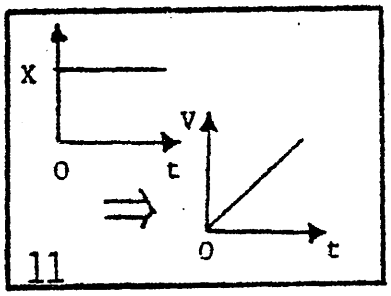


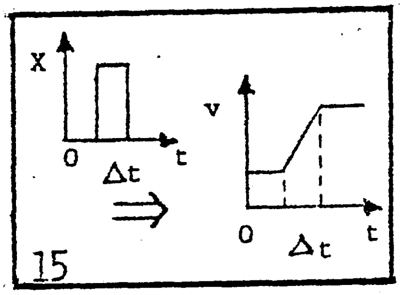


kinetic energy (and/or force)

momentum, impulse (and/or force)

Two boxes, with quite different diagrams, referred to the same concept.

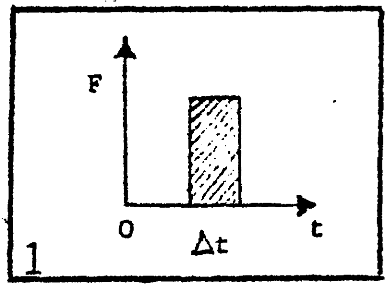


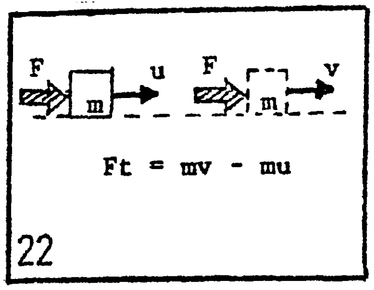


force

force (and/or impulse)

Two boxes gave exactly the same information. One box used a graph, the other used a labelled diagram and symbolic equation. Is there any significant difference in performance?





impulse, momentum (and/or force)

impulse, momentum (and/or force)

Finally, three boxes conveyed the same information in slightly different ways, to check if there was any marked variation between O-Grade and H-Grade groups. We assumed that the O-Grade group would use box 6, while the H-Grade group would prefer box 12. How would either group react to box 24?

$$F = ma$$

6

force (O-Grade?)

$$F = \frac{d(mv)}{dt}$$

12

force (H-Grade?)

$$F = m\frac{dv}{dt}$$

24

force

(Boxes 12 and 24 are also related to momentum and, somewhat more tenuously, to impulse)

The order in which the various concepts appeared on the chart was quite arbitrary, except that we consciously tried to avoid having the same concept appearing in neighbouring boxes.

The boxes on the chart which related to each of the five concepts involved are given in Table 23. Some boxes on the chart related to more than one concept. Box 4, as explained earlier, did not relate to any of the concepts.

Table 23 - Boxes on chart related to each concept

Concept	Numbers of boxes relating to this concept
Momentum	1, 8, 12, 16, 18, 20, 21, 22, 24
Kinetic energy	2, 5, 7, 9, 13, 14, 19, 23, 25
Potential energy	7, 9, 10, 17, 19
Force	1, 3, 6, 11, 12, 13, 15, 21, 22, 24
Impulse	1, 12, 15, 20, 21, 22, 24

The administration of the test material

As previously described, there were no less than 30 versions of the test material. There were 15 copies of each version of the test booklet, making a total of 450 booklets in all. One complete set of booklets was kept for reference purposes, and the remaining 420 booklets were used in the field test. Each booklet was colour-coded according to the main concept being tested, and were distributed in sets of 30, as far as possible.

The material was trialled in five secondary schools in the Strathclyde Region. Two schools provided both O-Grade and H-Grade pupils; the remaining three schools were asked to provide only H-Grade pupils. There was no selection of pupils within a school. All the H-Grade pupils in all five schools and all the O-Grade pupils in two of the five schools took part in the field trial. In all, 105 O-Grade pupils and 172 H-Grade pupils were involved.

The field trial for the schools took place in the spring term of session 1979-80. In all cases, the school was allowed to administer the test at a time which suited them. The school was provided with the requisite number of test booklets in advance of the test. The booklets were arranged in sequential sets of 30, but the teachers were not informed of this. They were simply asked to distribute the booklets to the pupils in the same order. This arrangement made the administration of the test particularly easy for the teacher and, at the same time, ensured that the different versions of the test booklet were evenly distributed throughout the group of pupils involved. Since the test booklets had covers of different colours, it was immediately obvious to the pupils that the booklets were not all the same, and thus the prospect of collaboration in answering was reduced.

We were present, as observers, during the actual test in the first two schools. The administration of the test was carried out by the class teacher. The pupils were allowed as much time as they wished to complete the test, but in all cases, they had finished the test in some 30-35 minutes. The teacher was not required to give additional verbal instructions and it was clear from the way the pupils completed the test, that the written instructions were more than adequate. At the request of the teacher, one change was agreed in the procedure. The O-Grade pupils were specifically instructed to ignore the boxes related to the concept of <u>impulse</u> in part 2 of the test, since this concept was not taught until H-Grade. Some O-Grade pupils, of course, were given a test booklet in which impulse was the chosen concept in part 1. No special allowance was made for this.

The pupils took the test very seriously and, from the expressions on their faces and the deep silence which fell over the room, it was clear that they were engrossed in what they were doing. Two particular points were noted -

(1) The first statement - "The quantity X is proportional to the mass of a body" - caused great concern to many pupils who, to start with, could not think of any possible answer. Then they suddenly thought of one answer and, in many cases, this seemed to 'trigger off' several other possible answers. Once the pupil had, at least, one answer written down, the initial concern seemed to disappear completely. No pupil failed to come up with at least one answer (even though it was inappropriate), but many pupils spent an inordinate amount of time at the first statement.

(2) In part 2 of the test, the pupils were observed to consider the boxes on the chart in strict numerical order. This was later confirmed by the completed record sheets, in which it was noted that the box numbers were almost always in strict numerical order.

When the test was complete, we asked some of the pupils what they thought of the material. They thought it was difficult, but challenging. They generally enjoyed doing the test, and would like to try more tests of this form. They particularly wanted to know the 'correct' answers for part 2 of the test.

We also asked the teachers for their comments, especially the teachers who had been persuaded to complete one of the test booklets along with the pupils. The teachers agreed that the test material was of value. In particular, they were impressed by the way the pupils had reacted to the material. This, to the teachers, was a positive asset of the material. Having glanced over some of the completed response sheets for part 2, they were somewhat concerned to note the clear misconceptions which were evident in some pupils' responses and would have liked to follow these up immediately. The nature of the field trial did not permit this, but it was clear that the teachers saw value in the diagnostic information about individual pupils which had emerged from the test.

The first trial of the test material had produced encouraging results. It was easy to administer, the pupils liked doing the test and the teachers were interested in the results. We decided to leave the other schools to run the test by themselves, to check that such results were not due, in some way, to our presence during the test. The tests were carried out in the other schools without any problem. Our only involvement was to answer a telephone query from one teacher. It appeared that some of his pupils had not completed the test in a single period (35 minutes). Would it be in order to give them more time, since they were keen to complete the test?

In the summer term of 1979-80, three other groups of students tried out the test material. A group of 34 First Year B.Sc. Physics students at Glasgow University, a group of 39 First Year Higher National Diploma (H.N.D.) in Applied Physics students at Glasgow College of Technology and a group of 19 student teachers at Jordanhill College of Education took part in this trial. The B.Sc. and H.N.D. students were chosen because they were specialising in physics, but the student teachers (all of whom were graduates in Chemistry or Biology) were chosen because they had not specialised in physics.

During the school trials of the material, we had invited the teachers supervising the test to work through the material. Some had accepted the invitation and, during the summer term of 1979-80, we persuaded a few more of our colleagues to work through the material. This group of specialist teachers of physics, 11 in all, was the smallest of the trial groups, but, as we will describe later, it was in some ways the most important trial group.

Table 24 shows a summary of the groups tested in the 1979-80 field trial.

Table 24 - Details of test population used in the 1979-80 trial

Concept Group	Mom'tum	K.E.	P.E.	Weight	Force	Impulse	Total
O-Grade pupils	22	18	14	20	15	16	105
H-Grade pupils	26	28	29	31	29	29	172
HND students	7	6	5	7	7	7	39
B.Sc.students	5	7	7	6	5	4	34
Student teachers	3	3	3	4	3	3	19
Teachers	3	1	4	0	1	2	11
Total	66	63	62	68	60	61	380

It will be noted from Table 24 that each of the six concepts is being tested on a representative sample of the total test population.

The results obtained in Part 1 of the test material

It is difficult to find a method of summarising the great amount of empirical data which was obtained from Part 1 of the test without, at the same time, losing sight of the important individual variations in the pattern of responses, and the unique relationship of the 'confidence rating' to a particular set of responses. We did consider, at one stage, using the Statistical Package for the Social Sciences (SPSS) to carry out a detailed statistical analysis of the data, but decided not to use this computer program for two reasons. In the first place, we would have required to encode all the data for the computer. This would, we calculated, require at least 6 punched cards per test booklet, or over 2000 cards in all - a formidable task for someone who had never operated a punch-card machine. More importantly, perhaps, we realised that, once the data was encoded into the computer, it would be difficult to avoid concentrating on 'common features' of the data as a whole and, by so doing, to under-estimate the importance of individual variations.

We started by transferring the data from the test booklets onto summary record sheets. As we did this, we became more interested in the idiosyncratic variations which were evident, particularly in the 'confidence rating' of each response. We began to look for reasons to explain these variations and to infer, from certain frequently occurring patterns of responses, that particular statements were more likely to cause a sudden 'drop' in the confidence rating than others. It was at this stage that we decided not to use the SPSS package but to continue to look closely at the individual response patterns, which were now more easily compared once the data had been entered on the summary record sheets.

In chapter 5, we suggested that the number of 'valid' responses the pupil makes to, say, the first statement could be an indication of the pupil's 'breadth' of understanding. A pupil who can provide, say, three 'valid' concepts in response to the statement "The quantity X is proportional to the mass of a body" has, we would suggest, a broader conceptual understanding than the pupil who can only suggest 'acceleration' or 'velocity' as possible concepts.

Table 25 shows, for each group, the total number of responses to the statement "The quantity X is proportional to the mass of a body", and the total number of 'valid' responses. The following responses were accepted as 'valid':

momentum, kinetic energy, potential energy, weight, density, centripetal force, angular momentum, moment of inertia.

velocity, acceleration, gravity, inertia,* friction, force, impulse, specific heat capacity, latent heat capacity and temperature change were not accepted as 'valid' responses.

Table 25 - Number of responses per group

Group	Number in Group	Total No. of responses	Total 'valid' responses	Percentage of 'valid' responses
O-Grade pupils	71	215	81	38
H-Grade pupils	113	380	183	48
HND students	25	57	30	53
B.Sc. students	25	53	35	66
Student teachers	13	24	14	58
Teachers	8	36	27	75
Total	255	765	370	48

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* It can be argued that inertia should have been accepted as a 'valid' response.

Although, on average, the O-Grade pupils gave more total responses than, say, the B.Sc. students, the majority of the O-Grade pupils' responses were invalid. (For example, '<u>acceleration</u>' appeared 36 times, '<u>velocity</u>' appeared 20 times, and '<u>force</u>' appeared 35 times) The B.Sc. students, on the other hand, gave a greater proportion of 'valid' responses, including for example, '<u>moment of inertia</u>', '<u>centripetal force</u>' and '<u>angular momentum</u>'. The teachers gave, an average, significantly more responses than any other group. In terms of the percentage of 'valid' responses given, the teachers and the B.Sc. students were significantly better ($p < 0.01$) than any other group.

<u>Table 26</u> shows, for each group, the total number of responses given to the statement "the quantity X is related to the mass of a body", and the total number of 'valid' responses. Since '<u>force</u>' and '<u>impulse</u>' are now considered 'valid' responses, the percentage of 'valid' responses, for each group, is greater than in <u>Table 25</u>.

<u>Table 26 - Number of responses per group</u>

	Number in group	Total No. of responses	Total 'valid' responses	Percentage of 'valid' responses
O-Grade pupils	34	111	54	49
H-Grade pupils	59	185	130	70
HND students	14	40	31	77
B.Sc. students	9	27	21	79
Student teachers	6	9	6	67
Teachers	3	12	10	83
Total	125	384	252	66

('<u>acceleration</u>' could also now be considered a 'valid' response).

Again, as in Table 25, the teachers and the B.Sc. students give a significantly greater percentage ($p < 0.01$) of 'valid' responses. The O-Grade pupils now show a significantly smaller percentage ($p < 0.01$) of 'valid' responses than any other group. This may be explained by the fact that no O-Grade pupil could suggest 'impulse' as a possible response, since this concept is not introduced until H-Grade.

As the number of statements increases, so the number of 'valid' responses decreases and, after a certain number of statements for each concept, there is only one 'valid' response possible. In the next set of tables, we show, for each group, the proportion of 'valid' responses at each separate statement. We would expect the proportion of 'valid' responses to increase progressively.

Table 27 - Proportion of 'valid' responses for 'momentum'

	No. in	Statement number								
Group	group	1	2	3	4	5	6	7	8	9
O-Grade pupils	22	0.5	0.6	0.8	0.7	0.5	0.5	0.6	0.8	0.6
H-Grade pupils	26	0.5	0.6	0.8	0.9	0.7	0.8	0.8	1.0	1.0
HND students	7	0.6	0.8	1.0	0.9	0.9	0.9	0.9	1.0	1.0
B.Sc. students	5	0.7	0.7	0.8	0.8	1.0	1.0	1.0	1.0	1.0
Student teachers	3	0.3	0.5	0.8	1.0	0.3	0.3	0.5	0.5	1.0
Teachers	3	0.8	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total	66	0.5	0.6	0.8	0.8	0.6	0.7	0.7	0.9	0.9

Two points should be noted from Table 27:

(i) With the exception of the O-Grade group, the proportion of 'valid' responses reaches the expected maximum value of 1.0. The B.Sc. students reach this level at statement 5, the teachers reach this level at statement 3.

(ii) There is a marked drop in the proportion of 'valid' responses at statement 5, for the O-Grade pupils, the H-Grade pupils and the student teachers. The statement which is causing difficulty is :

5. "The quantity X increases when a force is applied to a body, as indicated below:-

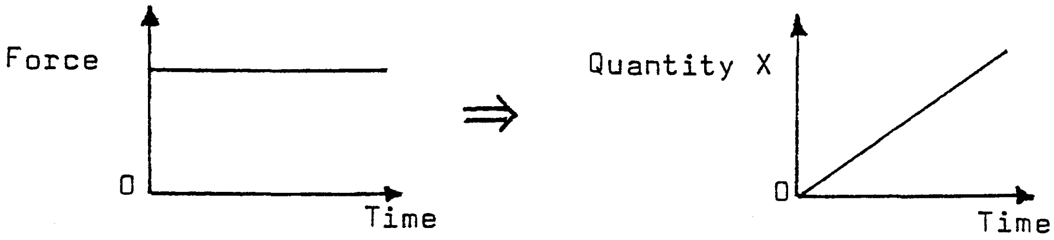
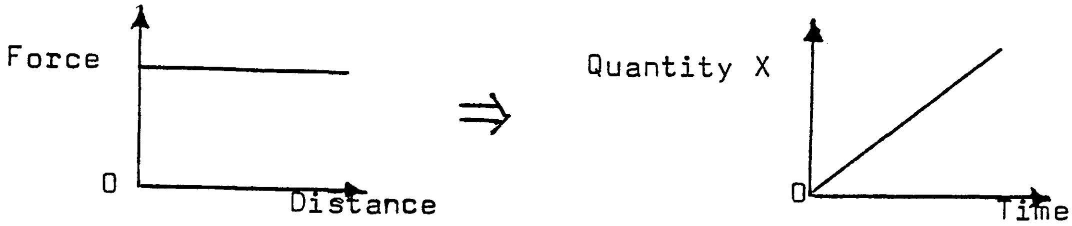


Table 28 - Proportion of 'valid' responses for 'kinetic energy'

Group	No. in group	statement number 1	2	3	4	5	6	7	8	9
O-Grade pupils	18	0.3	0.4	0.7	0.6	0.2	0.4	0.3	0.5	0.9
H-Grade pupils	28	0.5	0.6	0.8	0.7	0.5	0.7	0.8	0.9	1.0
HND students	6	0.5	0.7	1.0	1.0	0.3	0.3	0.7	0.7	1.0
B.Sc. students	7	0.6	0.7	0.9	0.9	0.4	0.5	0.8	1.0	1.0
Student teachers	3	0.5	0.6	1.0	1.0	0.3	0.0	0.2	0.0	0.6
Teachers	1	0.5	0.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0
Total	63	0.5	0.6	0.8	0.7	0.4	0.5	0.6	0.7	0.9

There is a marked drop in the proportion of 'valid' responses at statement 5 for all groups. The reason for this, we believe, is not statement 5 by itself. It is more likely the juxta position of statements 4 and 5 which is causing the problem.

4. "The quantity X increases when a force is applied to a body, as indicated below:-



5. "The change produced in the quantity X is a measure of the work done by the applied force"

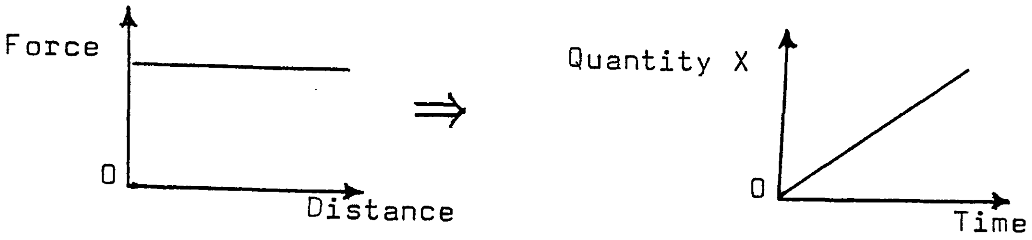
Table 29 - Proportion of 'valid' responses for 'potential energy'

Group	Number in group	statement number 1	2	3	4	5	6	7	8	9
O-Grade pupils	14	0.4	0.4	0.2	0.4	0.5	0.9	0.8	0.7	0.8
H-Grade pupils	29	0.5	0.6	0.7	0.8	0.4	0.4	0.8	0.9	1.0
HND students	5	0.7	0.8	0.6	0.6	0.6	0.8	0.8	0.8	1.0
B.Sc. students	7	0.8	0.8	0.3	0.4	0.6	1.0	1.0	1.0	1.0
Student teachers	3	0.6	0.3	0.3	0.0	0.5	0.7	0.0	0.7	1.0
Teachers	4	0.8	0.9	1.0	1.0	0.8	1.0	1.0	1.0	1.0
Total	62	0.6	0.6	0.6	0.7	0.5	0.8	0.8	0.8	1.0

The problem statements for potential energy seem to be 3, 4 and 5. This is particularly clear in the pattern of responses for the B.Sc. students, but all groups, apart from the teachers, show a similar pattern. It is not until statement 6 that we see a marked increase in the proportion of 'valid' responses.

It has since been pointed out that, in statement 4 for 'kinetic energy' and statement 3 for 'potential energy', the graph showing how the quantity X increases with time should not be a straight line. In each case, the energy increases as the square of the time. This would explain why these statements caused problems for all groups, as indicated in Tables 28 and 29.

3. "The quantity X increases when a force is applied to a body, as indicated below:-



4. "The change produced in the quantity X is a measure of the work done against gravity."

5. "The quantity X depends on the position of the body."

Table 30 - Proportion of 'valid' responses for 'weight'

Group	Number in group	Statement number 1	2	3	4	5	6	7	8	9
O-Grade pupils	20	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.7	0.6
H-Grade pupils	31	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.8	0.9
HND students	7	0.4	0.6	0.6	0.7	0.7	0.7	0.7	1.0	1.0
B.Sc. students	6	0.6	0.7	0.8	0.9	0.6	0.6	0.6	0.9	0.7
Student teachers	4	0.8	0.8	1.0	0.0	0.7	0.8	0.7	0.7	0.8
Teachers	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	68	0.4	0.6	0.6	0.6	0.5	0.5	0.5	0.8	0.8

This is an interesting situation. It is quite clear from the pattern of responses for all groups, that '<u>weight</u>' was not the first name that came into most pupils' (or students') minds. Indeed '<u>the force due to gravity</u>' and '<u>gravitational force</u>' appeared more frequently than did 'weight'. We accepted these as 'valid', but could not accept just '<u>force</u>' or '<u>gravity</u>'.

We were surprised to find that very few pupils or students seemed to use the term '<u>weight</u>' in the same sort of way as they used such terms as '<u>force</u>' or '<u>momentum</u>' . The pattern of responses indicated that, at a fairly early stage, most pupils/students knew the required concept involved '<u>force</u>' and '<u>gravity</u>', but they did not seem able to connect it with '<u>weight</u>' - hence the rather involved circumlocutions.

The crucial statement, in our opinion, was statement 4:

"The horizontal component of the quantity X is always zero".

It was interesting to note that this statement meant nothing at all to the student teachers.

Table 31: Proportion of 'valid' responses for 'force'

Group	Number in group	Statement number 1	2	3	4	5	6	7	8	9
O-Grade pupils	15	0.6	0.7	0.8	0.8	0.6	0.2	0.4	1.0	1.0
H-Grade pupils	29	0.7	0.8	0.9	0.9	0.8	0.6	0.4	0.7	0.9
HND students	7	0.7	1.0	1.0	1.0	0.9	0.4	0.4	1.0	1.0
B.Sc. students	5	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Student teachers	3	0.8	1.0	1.0	1.0	0.7	0.7	0.7	1.0	1.0
Teachers	1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total	60	0.7	0.8	0.9	0.9	0.7	0.5	0.5	0.9	0.9

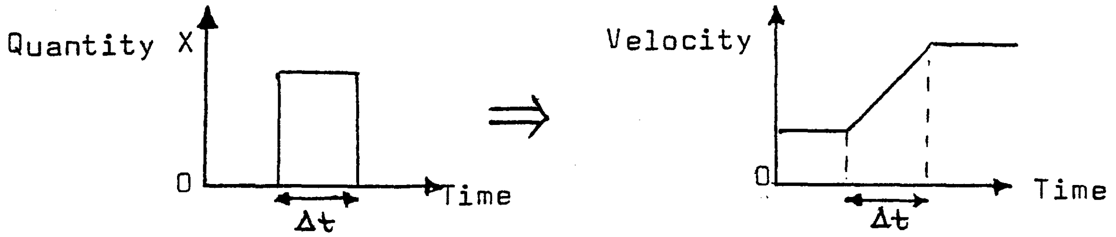
Three points should be noted from Table 31:

(i) There is no evidence to suggest that the first statement "The quantity X is related to the mass of a body" was misleading

(ii) The B.Sc. students gave several 'valid' alternative answers to the first few statements. It is only by statement 6 that they narrow the choice down to '<u>force</u>' (The teacher gave only one response at every stage)

(iii) Statements 5,6 and 7 give some problems to the other groups

5. "The change in velocity corresponding to a change in the quantity X is indicated below:-



6. "The quantity X is measured by the rate of change of momentum"

7. "The quantity X is a vector quantity"

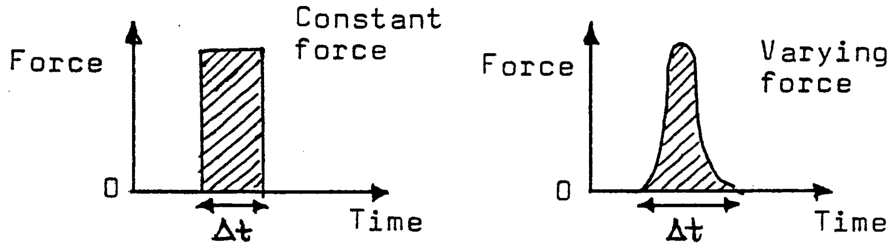
Table 32 - Proportion of 'valid' responses for 'impulse'

Group	Number in group	Statement number 1	2	3	4	5	6	7	8	9
O-Grade pupils	16	0.4	0.8	0.8	0.8	0.5	0.1	0.0	0.0	0.0
H-Grade pupils	29	0.7	0.8	0.7	0.8	0.7	0.6	0.6	0.8	0.9
HND students	7	0.9	0.9	0.9	0.9	0.7	0.7	0.7	0.7	0.7
B.Sc.students	4	0.7	1.0	0.8	1.0	1.0	1.0	1.0	1.0	1.0
Student teachers	3	0.5	0.8	0.7	0.3	0.3	0.3	0.0	0.0	0.0
Teachers	2	0.8	1.0	1.0	1.0	1.0	0.5	1.0	0.5	1.0
Total	61	0.6	0.9	0.8	0.8	0.6	0.5	0.5	0.5	0.6

The O-Grade pupils cannot be expected to recognise the concept involved here is 'impulse', since they will not yet have met this concept. The student teachers, who are not physics specialists, have clearly not heard of 'impulse' either, or possibly have long since forgotten about it.

Statement 5 seemed to cause some difficulty, although we had thought earlier that it was a rather obvious 'clue'.

5. "If a force is applied to a body, the quantity X is indicated by the shaded area".



We noted, with interest, that the statements which seemed to give most problems were, in all cases, the ones which involved sketch graphs. Clearly both pupils and students are likely to find these difficult to interpret. It may be, as we have suggested in an earlier chapter, that a graph can present just too much information, in a symbolic, implicit form, for most pupils to assimilate. The problem may be one of 'information overload'.

We now report some individual response sequences to give some indication of both typical and atypical responses. Obviously we have been selective in what sequences of responses we have chosen to report, but we felt there would be little value in giving an exhaustive listing of all the possible variations. We think that the twenty examples which follow will give a very fair indication of the general pattern of results, and will demonstrate the value of the 'confidence rating' table which appeared on each page.

It will be recalled that a confidence level of '1' corresponded to the statement "I have no real idea, so I have just made a guess" and a confidence level of '5' corresponded to the statement "I know it is .... and I can prove it".

We start with three examples to show what we would call a 'typical' response pattern. In each case, the number of suggested concepts decreases steadily, as the subject is given more and more information, until only one concept remains. At the same time, the confidence level steadily increases, as the subject becomes more and more certain that he is correct. This pattern of responses was very typical of the teachers, the B.Sc. students and many of the H-Grade pupils and HND students.

1. Subject = Teacher — Quantity X = 'momentum'

Page	Quantity X	Confidence level
1	momentum, kinetic energy potential energy, weight, acceleration	1
2	momentum, kinetic energy, weight, acceleration	1
3	momentum, weight	2
4	momentum, weight	2
5	momentum	4
6	momentum	4
7	momentum	4
8	momentum	5
9	momentum	5

2. Subject = H-Grade pupil Quantity X = 'force'

Page	Quantity X	Confidence level
1	acceleration, force, momentum	1
2	momentum, force	1
3	force	2
4	force	3
5	force	3
6	force	4
7	force	4
8	force	5
9	force	5

3. Subject = B.Sc. student Quantity X = 'potential energy'

Page	Quantity X	Confidence level
1	weight, momentum, kinetic energy, potential energy	3
2	weight, momentum, kinetic energy, potential energy	3
3	momentum, kinetic energy, potential energy	3
4	potential energy, kinetic energy	3
5	potential energy	3
6	potential energy	4
7	potential energy	4
8	potential energy	4
9	potential energy	5

It is advantageous to start with several possible concepts and gradually narrow down the choice, as in the following example:

4. Subject = H-Grade pupil   Quantity X = 'kinetic energy'

Page	Quantity X	Confidence level
1	heat energy, kinetic energy, potential energy, momentum, impulse	1
2	momentum, kinetic energy, potential energy, impulse	1
3	momentum, kinetic energy	2
4	kinetic energy	2
5	kinetic energy	3
6	kinetic energy	4
7	kinetic energy	4
8	kinetic energy	5
9	kinetic energy	5

Starting with only one concept imposes certain restrictions. Of course, if the subject happens to choose the 'correct' concept to start with, then each successive statement will reinforce this choice, as the following example shows:

5. Subject = H-Grade pupil   Quantity X = 'momentum'

Page	Quantity X	Confidence level
1	momentum	2
2	momentum	2
3	momentum	4
4	momentum	4
5	momentum	4
6	momentum	5
7	momentum	5
8	momentum	5
9	momentum	5

More frequently, however, the initial concept turns out to be wrong. This eventually becomes obvious to the subject and he is forced to start again. The confidence level is typically low, as the following example shows:

6. Subject = O-Grade pupil Quantity X = 'kinetic energy'

Page	Quantity X	Confidence level
1	velocity	2
2	velocity	2
3	momentum	2
4	momentum	1
5	momentum	1
6	kinetic energy	2
7	kinetic energy	2
8	kinetic energy	2
9	kinetic energy	5

It should not be assumed that most O-Grade pupils tended to give only single responses. In fact, apart from the teachers group, the O-Grade pupils gave single responses less frequently than any other group. The B.Sc. students, on average, gave single responses more frequently than any other group.

What tended to characterise the O-Grade pupils was that they generally needed more information before they could confidently identify the quantity X. This is illustrated by the following example, in which the required concept ('momentum') is present at every step, but it is not until statement 8 that the pupil is sure of his answer.

7. Subject = O-Grade pupil Quantity X = 'momentum'

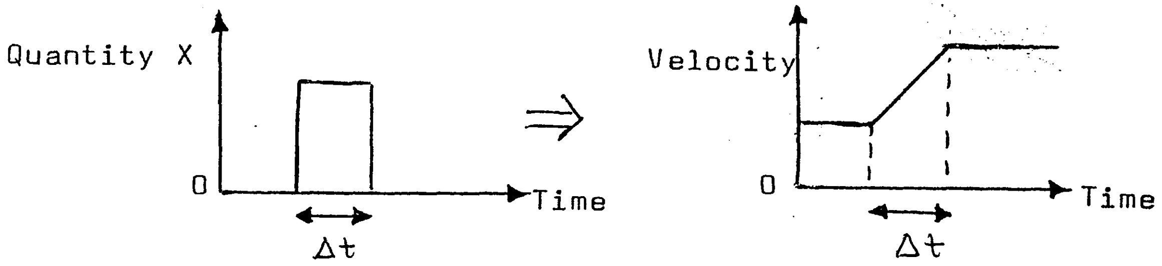
Page	Quantity X	Confidence level
1	force, weight, kinetic energy, momentum, pressure, volume	1
2	momentum, kinetic energy, potential energy, force	1
3	momentum, kinetic energy	2
4	momentum, kinetic energy	1
5	momentum, kinetic energy, acceleration	1
6	momentum, kinetic energy, acceleration	1
7	momentum	2
8	momentum	4
9	momentum	5

The O-Grade pupils tended to treat each statement on its own, and to respond with a concept which fitted that particular statement irrespective of whether or not it was compatible with previous statements. An H-Grade pupil, on the other hand, tended to use the given information to confirm his choice of concept. In the following three examples, the quantity X is force and, for reference, we have provided the nine statements. The O-Grade pupil tailors his response to suit the given statement. The H-Grade pupil makes one major 'course adjustment' at statement 5, but otherwise is using the given information to increase his 'confidence rating'. The B.Sc. student shows his understanding of statement 4 by including a further two valid concepts, but from then on he uses the information to confirm his final choice of 'force'.

The O-Grade pupil, until the other two, is never very confident that he has correctly identified the quantity X.

8. Subject - O-Grade pupil Quantity X = 'force'

Page	Statement	Quantity X	Confidence Level
(1)	The quantity X is related to the mass of a body	force, acceleration, gravity, potential	1
(2)	The quantity X is involved in both elastic and inelastic collisions	momentum, kinetic energy	1
(3)	The quantity X can be resolved into components	force	2
(4)	The quantity X can cause a body to undergo a change in velocity	force	2
(5)	The change in velocity corresponding to a change in the quantity X is indicated below	acceleration	2



Page	Statement	Quantity X	Confidence Level
(6)	The quantity X is measured by the rate of change of momentum	kinetic energy	1
(7)	The quantity X is a vector quantity	force, acceleration	1
(8)	The quantity X is measured in N	force	2
(9)	The quantity X is defined by the equation F = ma	force	4

9. Subject = H-Grade pupil   Quantity X = 'force'

Page	Quantity X	Confidence level
1	force, acceleration momentum, energy, velocity	2
2	velocity, momentum	3
3	momentum	3
4	momentum	4
5	force, momentum	3
6	force	4
7	force	4
8	force	5
9	force	5

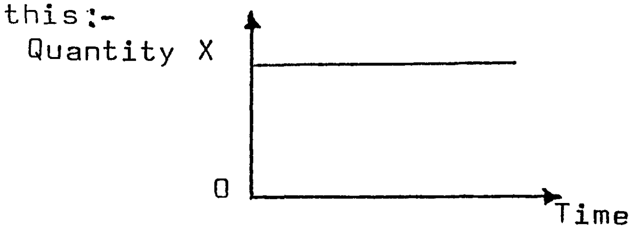
10. Subject = B.Sc.student   Quantity X = 'force'

Page	Quantity X	Confidence level
1	inertia, weight specific heat capacity, momentum, kinetic energy	2
2	momentum, kinetic energy	3
3	momentum	3
4	momentum, impulse, force	4
5	momentum, force	4
6	force	5
7	force	5
8	force	5
9	force	5

We have already noted that the term '<u>weight</u>' was not commonly used by any group. The following example illustrates this. The response '<u>acceleration due to gravity</u>' is perfectly valid, although unexpected. The term 'weight', however, is never mentioned.

There is one invalid response. '<u>Kinetic energy</u>' cannot be resolved into components (statement 3)

11. <u>Subject = H-Grade pupil</u> Quantity X = 'weight'

Page	Statement	Quantity X	Confidence level
1	"The quantity X is proportional to the mass of a body"	momentum, kinetic energy, potential energy, inertia, density, force	3
2	"The quantity X is possessed by moving bodies".	kinetic energy, momentum, force	3
3	"The quantity X can be resolved into components".	momentum, kinetic energy, force, acceleration due to gravity	3
4	"The horizontal component of the quantity X is always zero".	acceleration due to gravity	3
5	"The quantity X can cause a body to undergo a change of velocity".	acceleration due to gravity	4
6	"The graph of the quantity X against time looks like this:- 	acceleration due to gravity	4
7	"The quantity X is a vector quantity".	acceleration due to gravity	4
8	"The quantity X is measured in N".	force due to gravity	4
9	"The quantity X is defined by the equation W = mg".	force due to gravity	4

Statements about the concept '<u>impulse</u>'caused problems to O-Grade pupils and the student teachers, but the other groups had little difficulty. The following two examples, one for a student teacher and the other for an HND student, illustrate this.

12. <u>Subject = student teacher</u> <u>Quantity X = 'impulse'</u>

Page	Quantity X	Confidence level
1	force, gravity	5
2	force	4
3	force	5
4	force	5
5	momentum	4
6	impulse	1
7	force	2
8	momentum	4
9	momentum	4

It is interesting to note the high confidence level, except where she thinks the answer is '<u>impulse</u>'. The suggested responses are not, in fact, invalid in most cases for the particular statement they refer to.

13. <u>Subject = HND student</u> <u>Quantity X = 'impulse'</u>

Page	Quantity X	Confidence level
1	momentum, acceleration force, kinetic energy, potential energy	2
2	momentum, impulse, kinetic energy	3
3	momentum, kinetic energy	3
4	impulse, force	3
5	impulse	4
6	impulse	4
7	impulse	4
8	impulse	4
9	impulse	4

The student teachers provided some interesting response patterns. We must emphasis that they were all graduates and were therefore intellectually 'above average'. Most of them, however, had not done any physics since leaving school and had therefore had four years in which to forget what physics knowledge they might once have had. Their performance on the test material was not better than that of an O-Grade pupil, as the following examples shows:

14. Subject = Student teacher Quantity X = 'potential energy'

Page	Quantity X	Confidence level
1	force, kinetic energy	3
2	force	3
3	distance	1
4	distance	1
5	potential energy, kinetic energy	1
6	potential energy	1
7	momentum	1
8	potential energy	1
9	potential energy	5

We had earlier suggested that a sudden drop in the confidence rating would be indicative of a failure to match the information provided in the given statement to the particular concept the subject was thinking of. The following examples illustrate this situation.

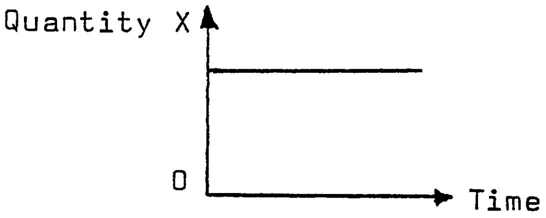
In each case, we have provided the statement which causes the sharp drop in the 'confidence rating'.

15. Subject = H-Grade pupil Quantity X = 'weight'

Page	Quantity X	Confidence level
1	force	3
2	momentum	3
3	momentum	2
4	force	3
5	force	4
6	potential energy	1
7	force	2
8	force	4
9	force	3

Statement 6 was:

6. The graph of the quantity X against time looks like this:-



16. Subject = H-Grade pupil   Quantity X = 'potential energy'

Page	Quantity X	Confidence level
1	force, acceleration	1
2	acceleration	2
3	acceleration	3
4	acceleration	4
5	mass	1
6	mass	1
7	mass	1
8	work done	1
9	potential energy	5

Statement 5 was:
"The quantity X depends on the position of the body"

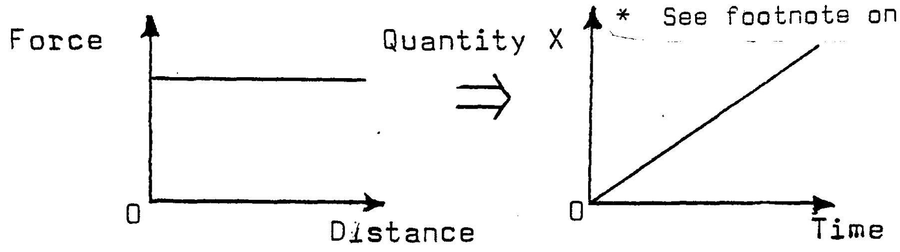
Statement 9 was:
"The quantity X is defined by the equation $E_p = mgh$"

17. Subject - H-Grade pupil   Quantity X = 'kinetic energy'

Page	Quantity X	Confidence level
1	velocity, kinetic energy acceleration, potential energy	3
2	kinetic energy, velocity momentum, acceleration	3
3	momentum, kinetic energy	4
4	momentum, kinetic energy	2
5	kinetic energy	4
6	kinetic energy	2
7	kinetic energy	4
8	kinetic energy	5
9	kinetic energy	5

Statement 4 was

4. "The quantity X increases when a force is applied to a body, as indicated below:-



* See footnote on page 183

Statement 6 was:-

6. "When a body is released from a height above the ground, the quantity X increases as the body falls.

Perhaps the most extreme fluctuation in 'confidence rating' was the following example:

18. Subject = H-Grade pupil   Quantity X = 'weight'

Page	Quantity X	Confidence level
1	force, momentum, potential energy	3
2	force, momentum kinetic energy	3
3	momentum, force	5
4	momentum	1
5	force	2
6	force	1
7	momentum	4
8	force	4
9	force	5

Statement 4 was
"The horizontal component of the quantity X is always zero"

Statement 7 was
"The quantity X is a vector quantity"
(Obviously this pupil recalls that 'momentum' is a vector quantity)

On occasions we noted our abrupt switch of the chosen concept without any corresponding variation in 'confidence level'. We noted that this generally happened towards the end of the sequence at, perhaps, statement 7 or 8. At this stage, the statements tend to be more specific and the subject may well realise that his suggested concept is wrong, and literally start again, greatly assisted now, of course, by having 7 or 8 statements to work with.

19. Subject = H-Grade pupil   Quantity X = 'kinetic energy'

Page	Quantity X	Confidence level
1	volume, density, acceleration, velocity, force, kinetic energy	2
2	kinetic energy, velocity, acceleration, density, volume, force	2
3	volume, density, momentum, velocity	2
4	momentum, acceleration, velocity	3
5	momentum	3
6	momentum	4
7	momentum	4
8	kinetic energy	4
9	kinetic energy	5

20. Subject = B.Sc. student   Quantity X = 'kinetic energy'

Page	Quantity X	Confidence level
1	acceleration	2
2	acceleration	3
3	momentum	5
4	momentum	5
5	momentum	5
6	momentum	5
7	kinetic energy	5
8	kinetic energy	5
9	kinetic energy	5

Conclusions from Part 1 of the material

1. Taking the number of 'valid' concepts suggested at statement 1 as a criterion of conceptual understanding, the teachers and the B.Sc. students were significantly better than the other groups.
2. The teachers and the B.Sc.students also identified the 'target' concept in significantly fewer statements
3. The O-Grade pupils required, on average, more statements before they could confidently identify the 'target' concept
4. The student teachers were no better than the O-Grade pupils
5. The interpretation of information presented graphically is likely to prove difficult to the majority of pupils
6. The term '<u>weight</u>' is not used by pupils in the same way they use such terms as '<u>force</u>' or '<u>momentum</u>'

On page 11 of the test booklet, the pupil/student was given a complete list of nine statements for another concept and was asked to tick a box to indicate the statement by which he identified the 'target' concept.

This part of the test was frequently misunderstood.

The pupils, in some cases, did not realise that the list of statements on page 11 referred to a <u>different</u> concept and gave their answer for the previous concept. Other pupils ticked several boxes, presumably indicating <u>all</u> the statements they would use to identify the concept. Still other pupils correctly identified the concept but failed to tick any box.

<u>Table 33</u> shows, for each group, the average number of statements required to identify the concept. The reliability of these figures is doubtful, but the trend seems to be that the O-Grade pupils generally require more statements to identify the concept than do the other groups.

(An entry of *** indicates failure to identify 'target' concept.)

Table 33 - Results for page 11 of Part 1

Concept Group	Momentum	K.E.	P.E.	Weight	Force	Impulse
O-Grade pupils	6.6	7.2	6.7	6.5	6.9	***
H-Grade pupils	5.8	5.3	5.8	6.3	6.5	6.3
HND students	3.6	5.8	5.5	6.5	4.3	6.5
B.Sc. students	5.1	6.4	5.5	7.0	4.0	6.5
Student teachers	9.0	4.2	8.5	4.5	***	***
Teachers	9.0	4.0	5.0	6.5	8.0	4.6
Mean value	5.8	6.0	6.1	6.1	6.0	6.1

The results obtained from Part 2 of the test material

The results from part 2 are summarised in Tables 34-38.

Table 34 shows the results for the concept of 'momentum' . The relevant boxes on the chart are shown in Figure 8.

Table 34 - Summary results for 'momentum'

BOX NUMBERS GROUP	N	1	8	12	16	18	20	21	22	24	14	5	13
O-Grade pupils	105	3 3	22 21	16 15	57 54	77 73	15 14	1 1	58 55	3 3	48 46	42 40	33 31
H-Grade pupils	172	50 29	88 51	54 31	142 83	147 85	26 15	87 51	105 61	29 17	42 24	32 19	47 27
HND students	39	10 26	24 62	14 36	34 87	21 54	4 10	15 38	24 62	7 18	14 36	16 41	12 31
B.Sc. students	34	12 35	21 62	25 74	34 100	31 91	8 24	24 71	24 71	4 12	7 21	3 9	2 12
Student teachers	19	3 16	4 21	4 21	12 63	10 53	3 16	2 11	6 32	2 11	6 32	7 37	2 11
Teachers	11	7 64	9 82	8 73	11 100	10 91	5 45	8 73	10 91	4 36	3 27	1 9	2 18
Total	380	85 22	168 44	121 32	290 76	296 78	61 16	137 36	227 60	49 13	120 32	101 26	100 26

MOST IMPORTANT

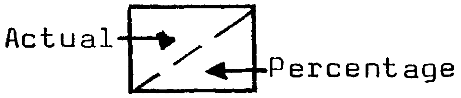


Figure 8 - Relevant boxes on chart for 'momentum'

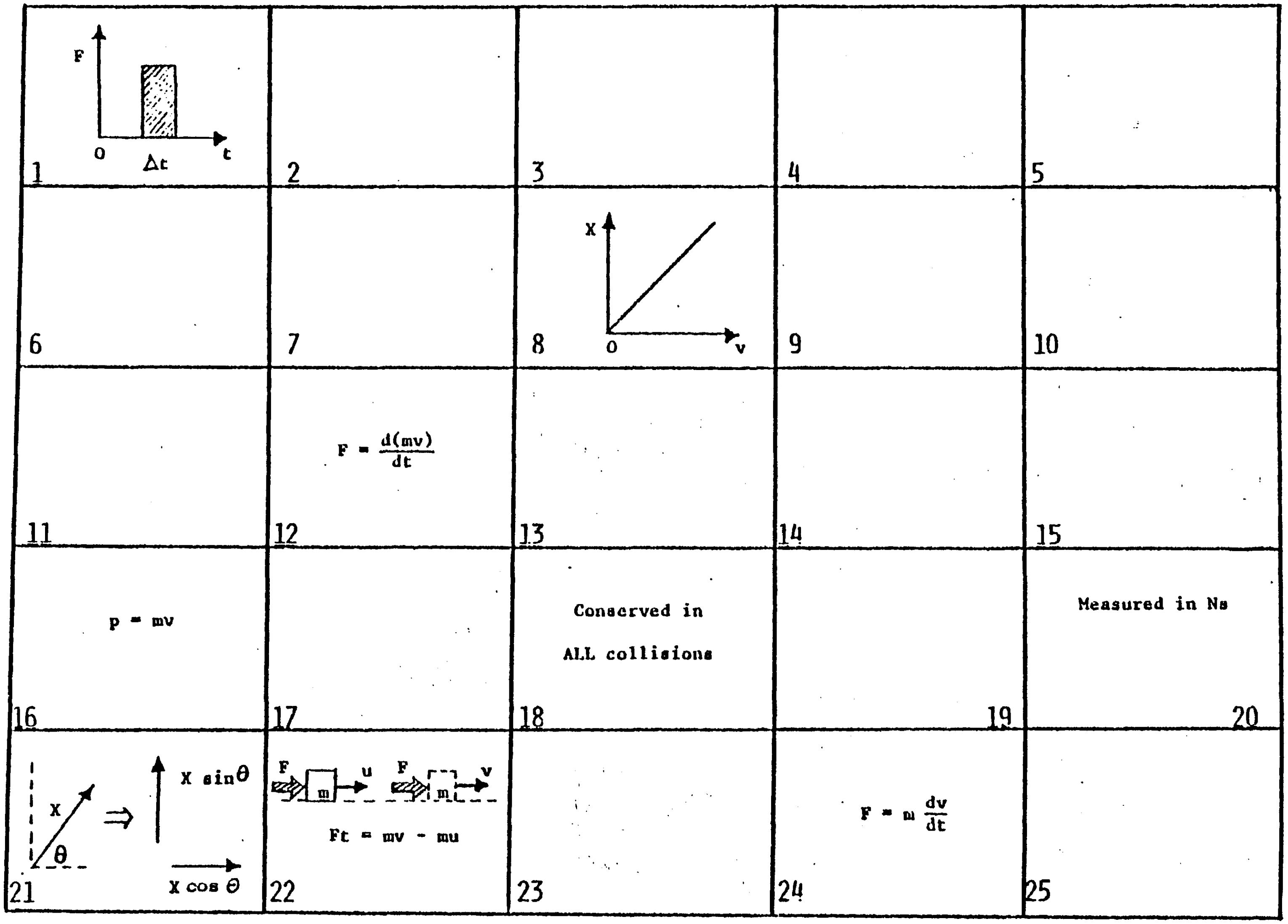


CHART FOR PART 2

The 'most important' boxes were box 16 and box 18. Box 16 contained the defining equation "p = mv" and box 18 contained the statement "Conserved in ALL collisions". The O-Grade pupils thought that box 18 was, perhaps, more important, while the HND students opted for box 16 as more important. There was no dispute, however, that these two facts about 'momentum' were more important than any other facts.

If the criterion of success is to include all the 'target' boxes, then the teachers were most successful, and the student teachers and the O-Grade pupils were least successful. In particular, the O-Grade pupils failed to include box 1, box 21 and box 24.

Table 34 also gives summary results for the three most frequently chosen boxes, other than the 'target' boxes. These boxes were particularly popular with the O-Grade and H-Grade pupils. Two of the boxes (14 and 5) refer to collisions, while box 13 refers to 'kinetic energy'. The most likely explanation for box 13 being so popular would be that the similar diagrams in boxes 13 and 22 encouraged pupils to include both boxes.

Table 35 shows the results for the concept of 'kinetic energy'. The relevant boxes on the chart are shown in Figure 9.

Table 35 - Summary results for 'kinetic energy'

BOX NUMBERS		2	5	7	9	13	14	19	23	25	8
GROUP	N										
O-Grade pupils	105	102 97	33 31	38 36	83 79	42 40	38 36	65 62	10 10	39 37	20 19
H-Grade pupils	172	170 99	133 77	105 61	163 95	83 48	89 52	134 80	74 43	124 72	31 18
HND students	39	39 100	21 54	24 62	37 95	23 59	18 46	33 85	21 54	21 54	7 18
B.Sc. students	34	34 100	29 85	26 76	33 97	30 88	21 62	29 85	22 65	27 79	1 3
Student teachers	19	17 89	9 47	3 16	14 74	9 47	8 42	10 53	2 11	8 42	3 16
Teachers	11	11 100	9 82	11 100	11 100	10 91	9 82	10 91	8 73	9 82	1 9
Total	380	373 98	234 62	207 54	341 90	197 52	183 48	281 74	137 36	228 60	63 17

⇧ MOST IMPORTANT ⇧

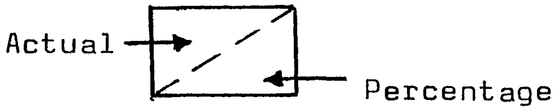


Figure 9 - Relevant boxes on chart for 'kinetic energy'

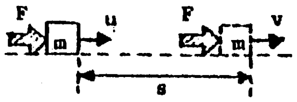
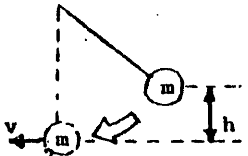
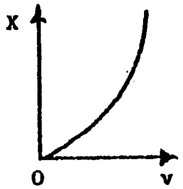
1	$E_k = \frac{1}{2}mv^2$ 2	3	4	Conserved ONLY in elastic collisions 5
6	A scalar quantity 7	8	Measured in J 9	10
11	12	 $Fs = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ 13	Increased in an explosive collision 14	15
16	17	18	 $\frac{1}{2}mv^2 = mgh$ 19	20
21	22	 23	24	Decreased in an inelastic collision 25

CHART FOR PART 2

The 'most important' box for 'kinetic energy' was box 2, which contained the defining equation "$E_k = \frac{1}{2}mv^2$", Box 9, which contained the statement "Measured in J" was also considered important by all groups, but the B.Sc. students and the teachers thought box 5, which contained the statement "Conserved ONLY in elastic collisions" and box 13, which indicated by a diagram that "work done = change in kinetic energy" were possibly more important than box 9.

In terms of including all the 'target' boxes, the teachers were most successful, but the B.Sc. students were not far behind. The student teachers and the O-Grade pupils were least successful. In particular the O-Grade pupils failed to include box 23.

Apart from the 'target' boxes, the most popular choice of box was, rather surprisingly, box 8. More O-Grade pupils chose box 8 than chose box 23. (This is more evidence that pupils find difficulty with the interpretation of sketch graphs).

Table 36 shows the results for the concept of 'potential energy'. The relevant boxes on the chart are shown in Figure 10.

Table 36 - Summary results for 'potential energy'

BOX NUMBERS		7	9	10	17	19	4
GROUP	N						
O-Grade pupils	105	29 28	67 64	94 90	85 81	68 65	12 11
H-Grade pupils	172	86 50	142 83	161 94	154 90	134 78	33 19
HND students	39	22 56	32 82	38 97	37 95	33 85	9 23
B.Sc.students	34	21 62	31 91	34 100	32 94	29 85	9 26
Student teachers	19	5 26	13 68	17 89	13 68	13 68	2 11
Teachers	11	10 91	10 91	11 100	11 100	11 100	2 18
Total	380	173 46	295 78	355 93	332 87	288 76	67 18

MOST IMPORTANT

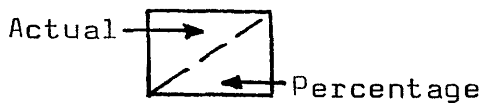
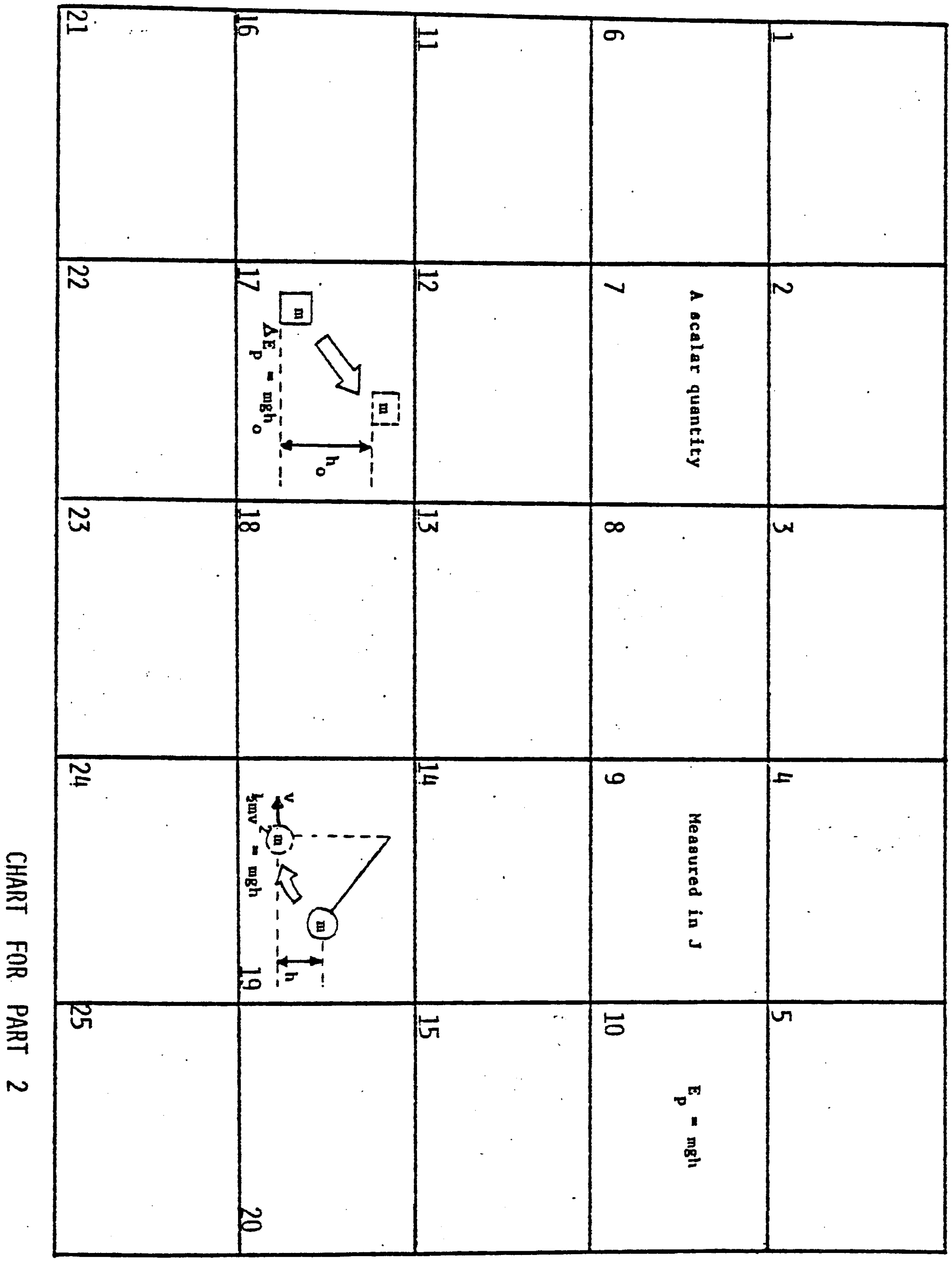


Figure 10 - Relevant boxes on chart for 'potential energy'



The 'most important' boxes for 'potential energy' were box 10, which contained the defining equation "E_p = mgh" and box 17, which indicated by a diagram how the change in potential energy was calculated.

In terms of including all the 'target' boxes, all the groups were successful. Box 7 seemed to be the only 'target' box which was not included by the majority of pupils. O-Grade pupils may not know the term 'scalar quantity'.

Box 4, which did not apply to any concept, was included by about 20% of H-Grade pupils and 25% of B.Sc. students. We can only assume they were making the same mistake as ourselves.

Table 37 shows the results for the concept of 'force'. The relevant boxes on the chart are shown in Figure 11.

Table 37 - Summary results for 'force'

BOX NUMBER		1	3	6	11	12	13	15	21	22	24	7
GROUP	N											
O-Grade pupils	105	38 / 36	97 / 92	104 / 99	15 / 14	65 / 62	35 / 33	15 / 14	16 / 15	39 / 37	71 / 68	22 / 21
H-Grade pupils	172	66 / 38	158 / 92	164 / 95	54 / 31	134 / 80	60 / 35	52 / 30	73 / 42	52 / 30	133 / 77	34 / 20
HND students	39	13 / 33	39 / 100	39 / 100	15 / 38	29 / 74	11 / 28	24 / 62	30 / 77	13 / 33	34 / 87	6 / 15
B.Sc.students	34	10 / 29	32 / 94	33 / 97	22 / 65	33 / 97	23 / 68	16 / 47	28 / 82	25 / 74	34 / 100	3 / 9
Student teachers	19	5 / 26	16 / 84	18 / 95	8 / 42	12 / 63	8 / 42	3 / 16	5 / 26	7 / 37	14 / 74	7 / 37
Teachers	11	7 / 64	11 / 100	11 / 100	7 / 64	11 / 100	10 / 91	7 / 64	9 / 82	8 / 73	11 / 100	1 / 9
Total	380	139 / 37	353 / 93	369 / 97	121 / 32	284 / 75	147 / 39	117 / 31	161 / 42	144 / 38	297 / 78	73 / 19

⇧ ⇧ MOST IMPORTANT

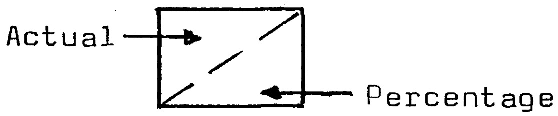


Figure 11 - Relevant boxes on chart for 'force'

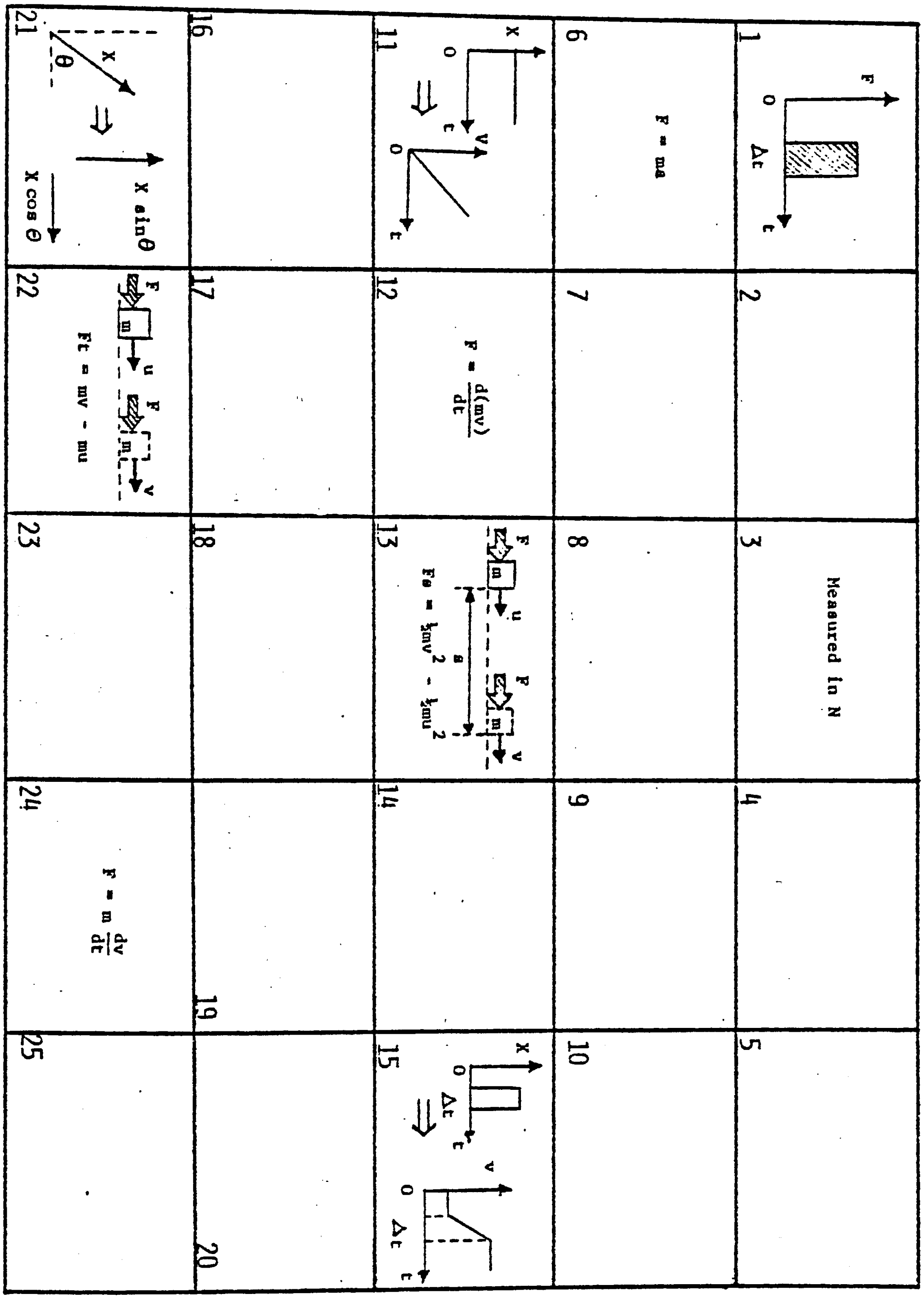


CHART FOR PART 2

The 'most important' boxes for '<u>force</u>' were box 6, which contained the defining equation "F = ma", and box 3 which contained the statement "Measured in N". The B.Sc. students and the teachers, however, were ofthe opinion that box 12, which contained an alternative form of the defining equation "$F = \frac{d(mv)}{dt}$" was more important than box 3. They also thought that box 21 and box 24 were just as important as box 3.

Boxes 11 and 15 were chosen with equal frequency.

In terms of including all the 'target' boxes, the teachers had a slight edge on the B.Sc. students. The O-Grade pupils were least successful.

Apart from the 'target' boxes, the most popular choice of box was, very surprisingly, box 7, which contained the statement "A scalar quantity". More student teachers thought box 7 applied to '<u>force</u>' than thought box 7 applied to '<u>potential energy</u>' or '<u>kinetic energy</u>' . There is some confirming evidence here that O-Grade pupils may not know what the term 'scalar quantity' means.

<u>Table 38</u> shows the results for the concept of '<u>impulse</u>'. The relevant boxes on the chart are shown in <u>Figure 12</u>.

Table 38 - Summary results for 'impulse'

BOX NUMBER												
GROUP	N	1	12	15	20	21	22	24	13	7	8	14
H-Grade pupils	172	130 76	89 52	44 26	140 81	18 10	118 67	50 29	52 30	41 24	26 15	16 9
HND students	39	13 33	14 36	9 23	24 62	7 18	19 49	5 13	10 26	10 26	7 18	11 28
B.Sc. students	34	28 82	16 47	7 21	29 85	12 35	23 68	10 29	1 3	6 18	6 18	3 8
Student teachers	19	5 26	2 11	3 16	8 42	0 0	5 26	1 5	1 5	1 5	2 11	0 0
Teachers	11	10 91	3 27	7 64	9 82	7 64	10 91	3 27	0 0	0 0	2 18	1 9
Total	275	186 68	124 45	70 25	210 76	44 16	175 64	69 25	64 23	58 21	43 16	31 11

MOST IMPORTANT

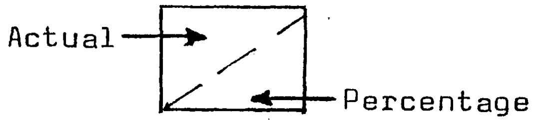


Figure 12 - Relevant boxes on chart for 'impulse'

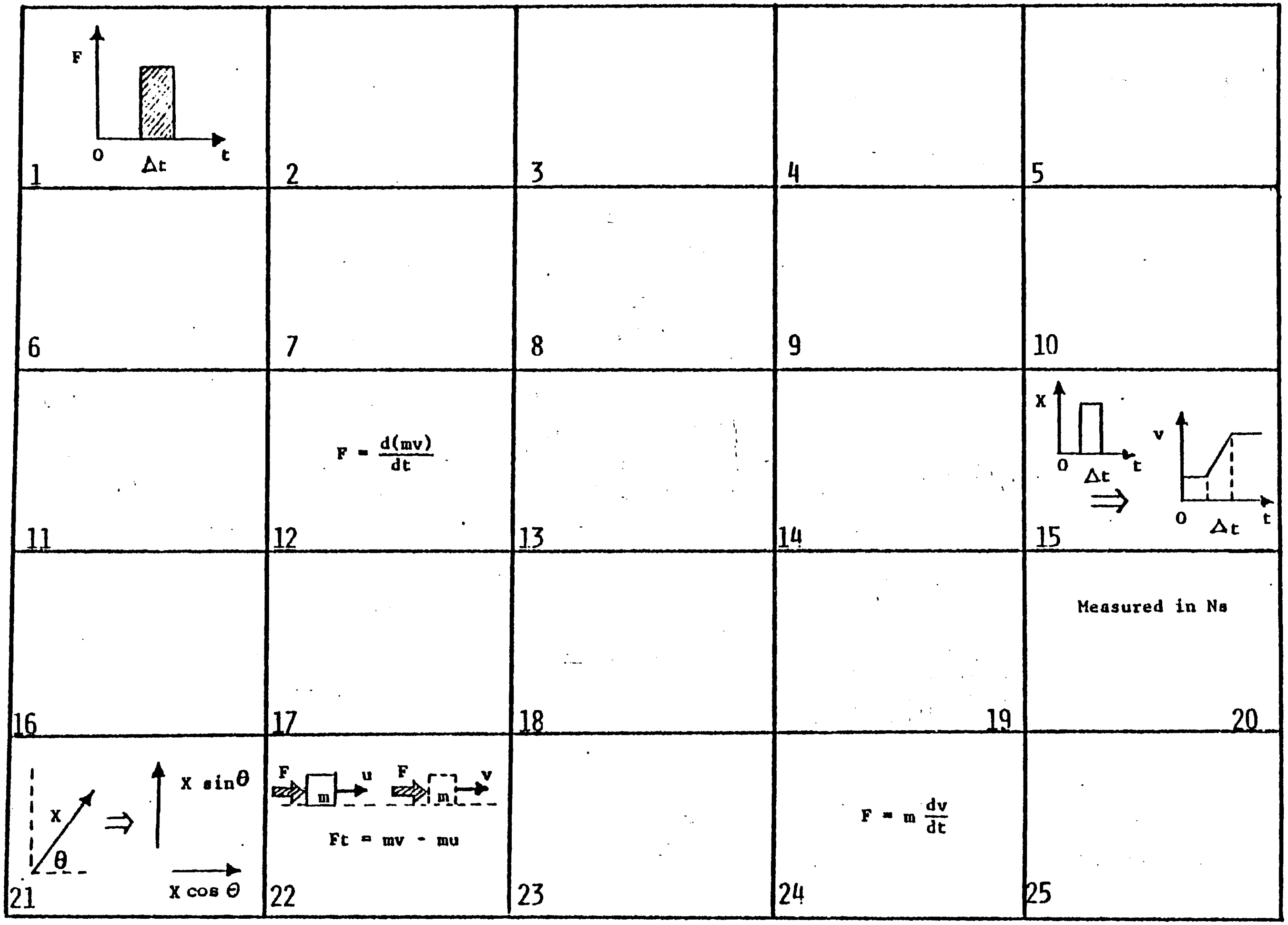


CHART FOR PART 2

The 'most important' boxes for 'impulse' was box 22, which shows by a diagram that "impulse = change in momentum", box 1, which showed by a shaded area on a force-time graph that "impulse = force x time", and box 20, which contained the statement "Measured in Ns" Boxes 22 and 1 were chosen with equal frequency. In terms of including all the 'target' boxes, no group were very successful. The teachers were probably most successful, but, on this occasion, the H-Grade pupils were slightly better than the B.Sc. students. The O-Grade pupils, of course, were told to omit this section, since they would not know about '<u>impulse</u>'. The student teachers should probably have been given the same instruction.

Apart from the 'target' boxes, there was a fair number of H-Grade pupils opting for box 13, which contained the same diagram as box 22, box 7, which contained the statement "A scalar quantity" and box 8 which showed a straight-line graph. Box 14, which contained the statement "Increased in an explosive collision" was also popular. This spread of choice would indicate that "<u>impulse</u>" is not fully understood by H-Grade pupils.

The record sheet on which the pupils noted the numbers of the chosen boxes for each concept, had 12 blanks for each concept. (We had calculated that no more than 10 would be needed.) If we count the number of boxes filled on this record sheet and, separately, count the number of 'valid' choices, we can get a measure of how often a 'valid' choice was made.

This is shown in <u>Tables 39-43</u>. For each concept, we have listed:

(A) - The actual numbers who filled in 1 or 2 or .... boxes on their record sheets

(B) - The actual numbers who included 1 or 2 or ..... of the 'target' boxes

(c) - The percentage of the group who included 1 or 2 or ...... of the 'target' boxes.

Line (C) for each group gives a measure of the overall level of performance of that particular group, and we can therefore compare the relative performance of the different groups by looking at the entries in line (C). In Table 39, for example, we can see that 83% of the H-Grade group included 3 of the 'target' boxes, compared with 43% of the O-Grade group and 91% of the B.Sc. group. We also note, from Table 39, that the H-Grade group performs consistently better than the O-Grade group, but generally not so well as the B.Sc. group.

14 18

For each concept, we have drawn, in Figures 13-17, a series of bar charts, based on the entries in each line (C) of Tables 39-43, to make the comparison between the groups somewhat easier. The pattern which emerges is remarkably similar for all five concepts.

The six different groups of subjects, in terms of level of overall performance, can be divided into three pairs.

(i) A student teacher is on a par with an O-Grade pupil
(ii) An HND student is on a par with an H-Grade pupil
(iii) A B.Sc. student is on a par with a teacher

There is a clear improvement in level of overall performance as we move from the O-Grade pupil to the H-Grade pupil to the B.Sc. student.

We might have anticipated that a B.Sc. student would perform better than an H-Grade pupil or that an HND student would perform better than an O-Grade pupil. We could hardly have anticipated that an HND student would be no better than an H-Grade pupil, or that a student teacher would be no better than an O-Grade pupil.

We could include in the chart for Part 2 only a selection of all the possible instances and non-instances of each concept. The fact that we obtain the same pattern of results for each separate concept indicates that

(i) even a small number of instances can provide a reliable indication of the level of concept understanding.

(ii) the technique is equally applicable to a number of different concepts.

(iii) the concepts being tested may have some common pattern of development.

Table 39 - Analysis of response sheet for 'momentum'

Number of 'valid' boxes = 9

NUMBER OF BOXES		0	1	2	3	4	5	6	7	8	9	10	11	12	Av.	%
O-Grade pupils (N=105)	(A)		2	7	13	26	20	20	6	7	4				4.9	
	(B)	4	24	32	22	19	3	1							2.4	49
	(C)		96	73	43	22	4	1								
H-Grade pupils (N=172)	(A)		1	4	23	30	25	36	15	16	16	3	3		5.7	
	(B)		9	20	42	31	34	13	14	3	6				4.2	74
	(C)		100	95	83	59	41	21	13	5	3					
HND students (N=39)	(A)				4	8	7	9	3	3	2	1		2	5.9	
	(B)		1	6	10	11	7	1	1	2					3.9	66
	(C)		100	97	82	56	28	10	8	5						
B.Sc. students (N=34)	(A)			1	4	3	2	6	13	4	1				6.0	
	(B)		1	2	4	2	2	14	8	1					5.4	90
	(C)		100	97	91	79	74	68	26	3						
Student teachers (N=19)	(A)	2	2	2	2	4	1	3	1		1		1		4.1	
	(B)	4	4	3	1	3	3	1							2.4	59
	(C)		79	58	42	37	21	5								
Teachers (N=11)	(A)						2	1	2	3	1		1		7.4	
	(B)					1	2	2	3	2	1				6.6	89
	(c)		100	100	100	100	91	73	54	27	9					

Figure 14 - Data from Table 39

CONCEPT : MOMENTUM

NUMBER OF 'VALID' BOXES = 9

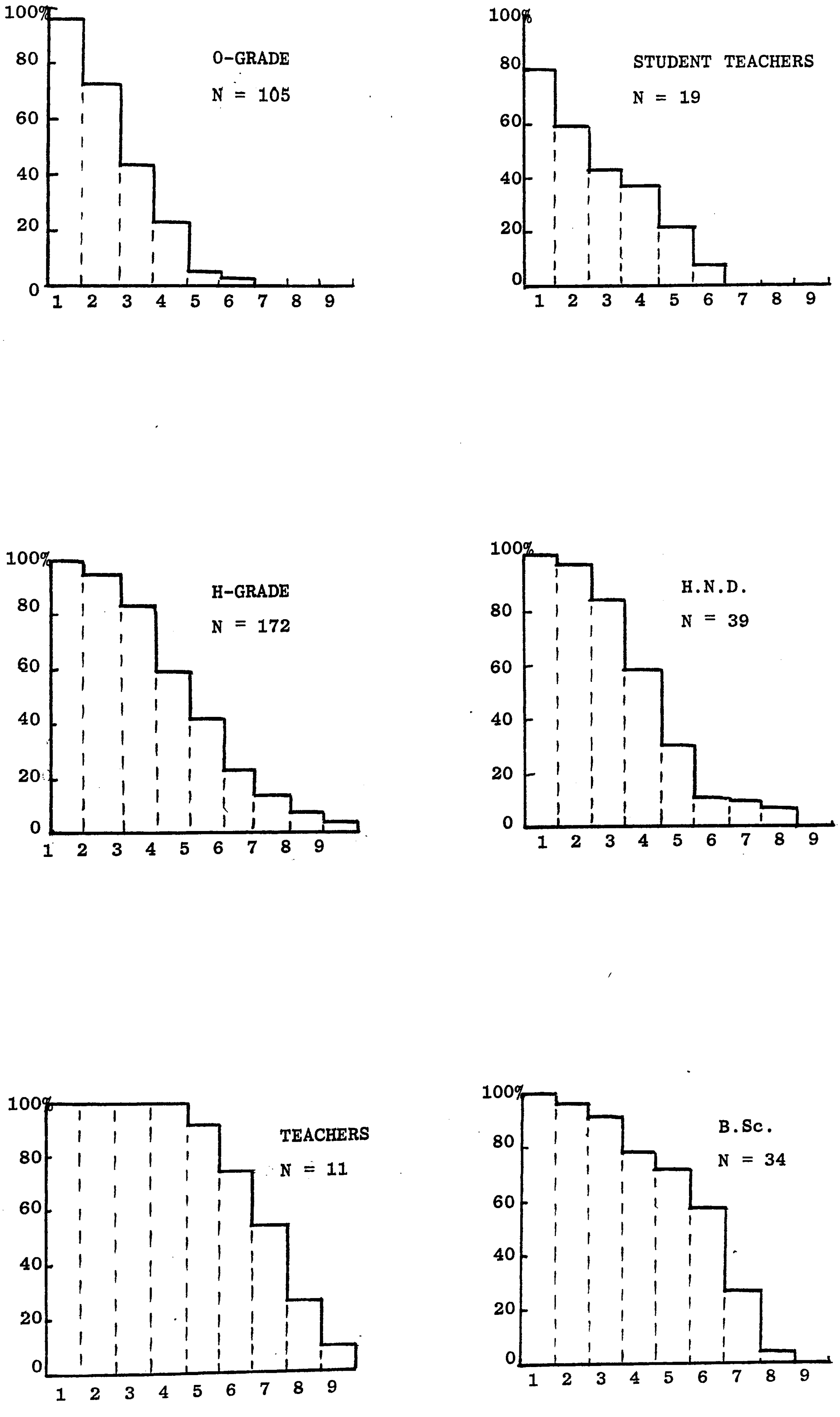


Table 40 - Analysis of response sheet for 'kinetic energy'

Number of 'valid' boxes = 9

NUMBER OF BOXES		0	1	2	3	4	5	6	7	8	9	10	11	12	Av.	%
O-Grade pupils (N=105)	(A)			6	14	25	25	13	14	4	3	1			5.0	
	(B)		3	11	14	34	20	15	7	1					4.3	86
	(C)		100	97	87	75	41	22	8	1						
H-Grade pupils (N=172)	(A)	1			2	17	19	32	38	36	18	4	4	1	6.8	
	(B)	1		1	14	26	42	34	31	14					6.3	93
	(C)		100	100	99	94	85	70	46	26	8					
HND students (N=39)	(A)					3	4	9	8	9	5		1		6.9	
	(B)				2	4	9	5	13	5	1				6.1	88
	(C)		100	100	100	95	85	62	49	15	3					
B.Sc. students (N=34)	(A)			1		2	1	2	7	7	11	3			7.7	
	(B)			1	1	1	2	2	7	8	12				7.4	96
	(C)		100	100	97	94	91	85	79	59	35					
Student teachers (N=19)	(A)	2	1	2	1		3	5	3	2					4.7	
	(B)	2	1	2	1	3	3	5	1	1					4.2	89
	(C)		89	84	74	68	53	37	11	5						
Teachers (N=11)	(A)								1	6	4				8.3	
	(B)							1	1	6	3				8.0	96
	(C)		100	100	100	100	100	100	91	82	27					

Figure 15 - Data from Table 40

CONCEPT : KINETIC ENERGY

NUMBER OF 'VALID' BOXES = 9

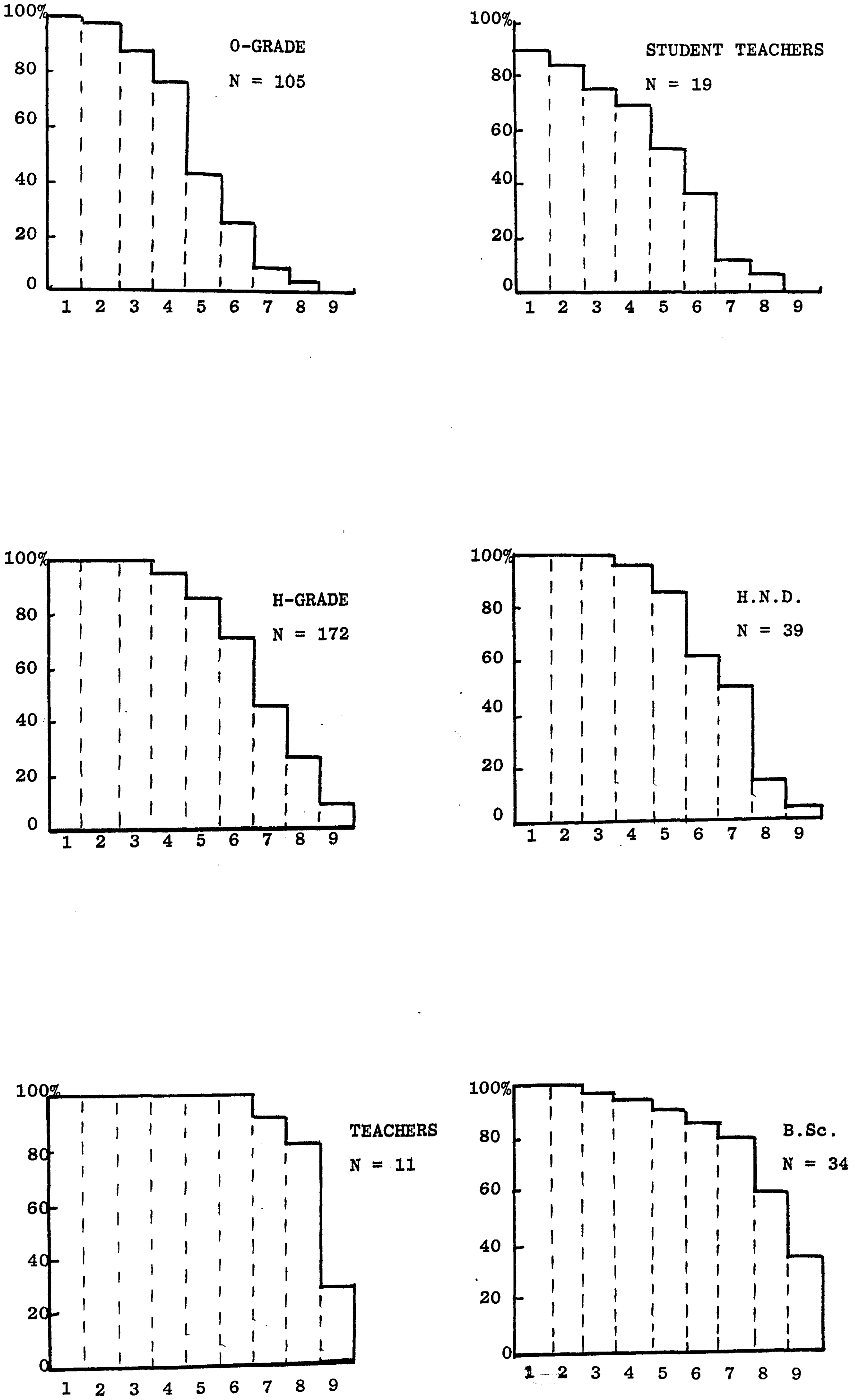


Table 41 - Analysis of response sheet for 'potential energy'

Number of 'valid' boxes = 5

NUMBER OF BOXES		0	1	2	3	4	5	6	7	8	9	10	11	12	Av.	%
O-Grade pupils (N=105)	(A)	1	2	7	22	34	24	10	3	2					4.1	
	(B)	4	3	19	29	39	11								3.2	78
	(C)		96	93	75	48	10									
H-Grade pupils (N=172)	(A)	2	2	2	20	53	56	29	7	1					4.6	
	(B)	2	5	5	36	63	61								4.0	87
	(C)		99	96	93	72	35									
HND students (N=39)	(A)				1	10	17	10	1						5.0	
	(B)			1	3	19	16								4.3	86
	(C)		100	100	97	90	41									
B.Sc. students (N=34)	(A)			1	2	6	17	5		2		1			5.1	
	(B)			1	4	12	17								4.3	84
	(C)		100	100	97	85	50									
Student teachers (N=19)	(A)		3	2	2	6	5	1							3.6	
	(B)	1	3	1	4	6	4								3.2	89
	(C)		95	79	74	53	21									
Teachers (N=11)	(A)					2	7	2							5.0	
	(B)					2	9								4.8	96
	(C)		100	100	100	100	82									

Figure 16 - Data from Table 41

CONCEPT : POTENTIAL ENERGY

NUMBER OF 'VALID' BOXES = 5

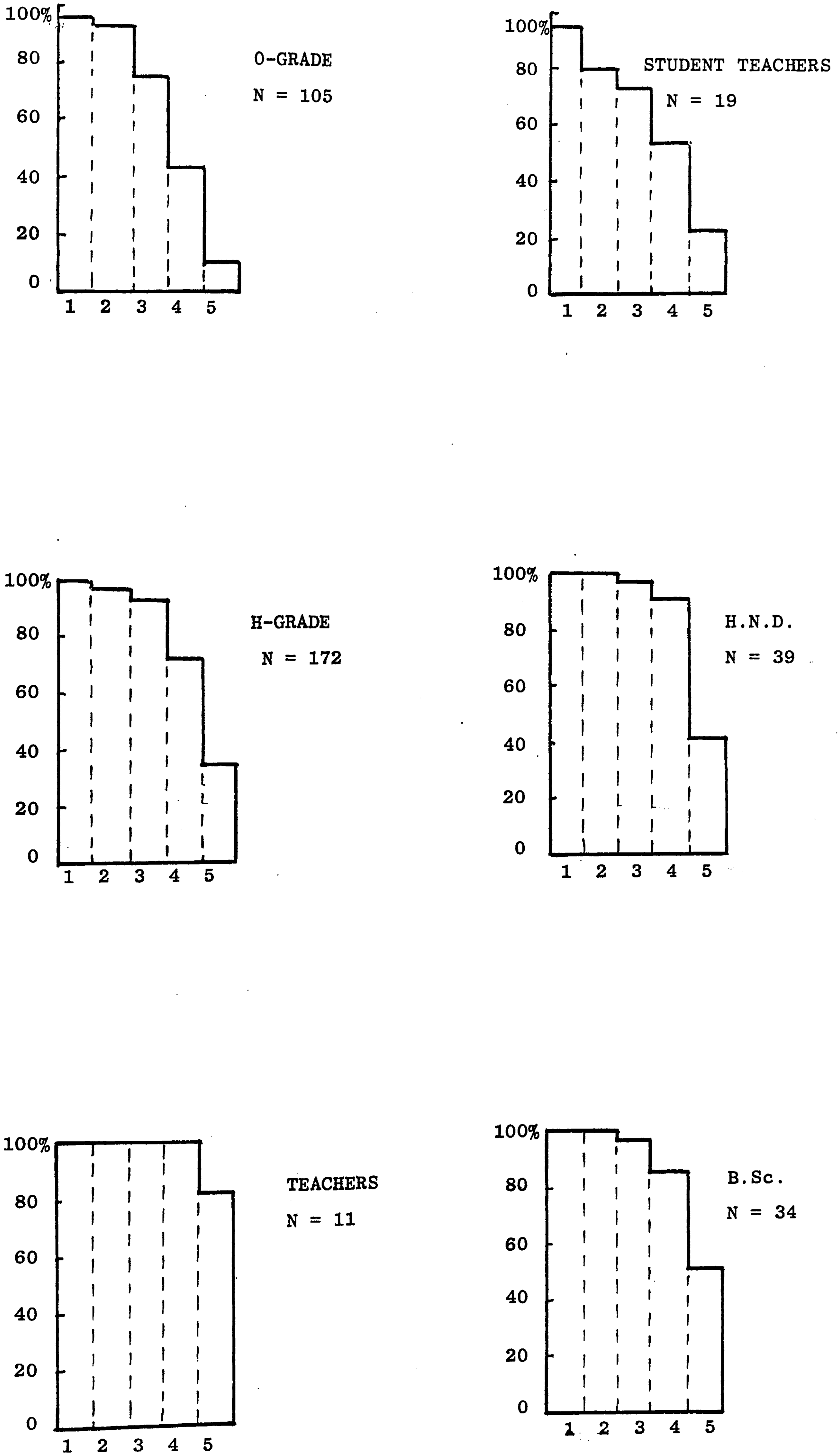


Table 42 - Analysis of response sheet for 'force'

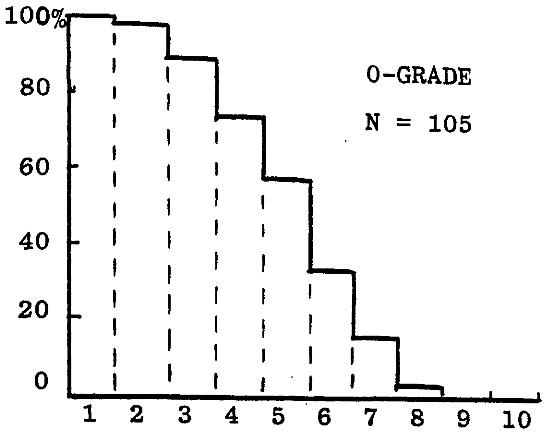
Number of 'valid' boxes = 10

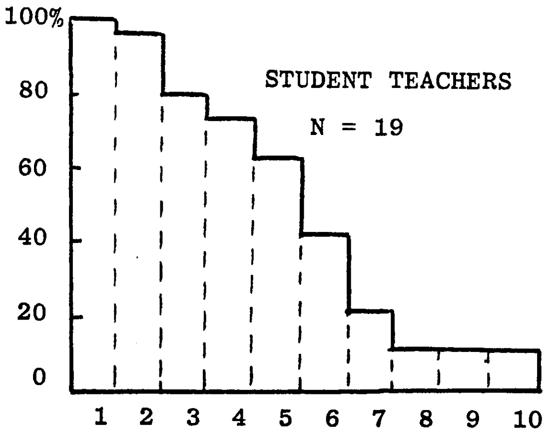
NUMBER OF BOXES		0	1	2	3	4	5	6	7	8	9	10	11	12	Av.	%
O-Grade pupils (N=105)	(A)		2	3	11	21	17	18	13	12	3	4		1	5.6	
	(B)		2	11	16	16	26	18	15	1					4.8	86
	(C)		100	98	88	72	57	32	15	1						
H-Grade pupils (N=172)	(A)	3		2	11	28	24	25	34	23	11	7	1	3	6.2	
	(B)	3		8	18	30	34	19	34	12	9	5			5.5	89
	(C)		98	98	94	83	66	46	35	15	8	3				
HND students (N=39)	(A)				3	4	6	7	8	3	3	3	1	1	6.6	
	(B)			1	3	5	6	7	8	3	3	3			6.2	94
	(C)		100	100	97	90	77	61	46	23	15	8				
B.Sc. students (N=34)	(A)	1				2	3	5		4	8	5	5	1	8.1	
	(B)	1			1	2	3	5	1	7	12	2			7.3	90
	(C)		97	97	97	94	88	74	59	56	41	6				
Student teachers (N=19)	(A)		1	3	1		5	2	3		2	1		1	5.7	
	(B)		1	3	1	2	4	4	2			2			5.1	89
	(C)		100	95	79	74	63	42	21	10	10	10				
Teachers (N=11)	(A)							1	2	1	3	1		3	9.2	
	(B)							1	2	3	2	3			8.4	91
	(C)		100	100	100	100	100	100	91	73	45	6				

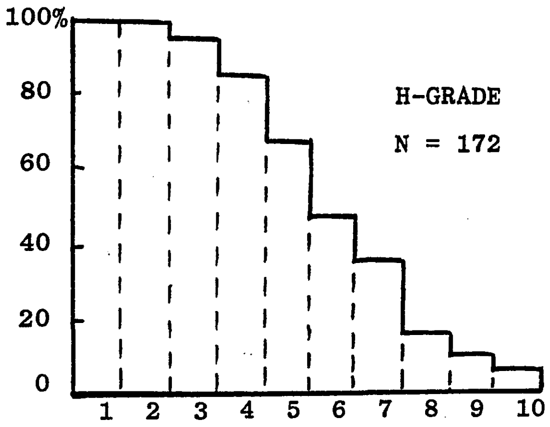
Figure 17 : Data from Table 42

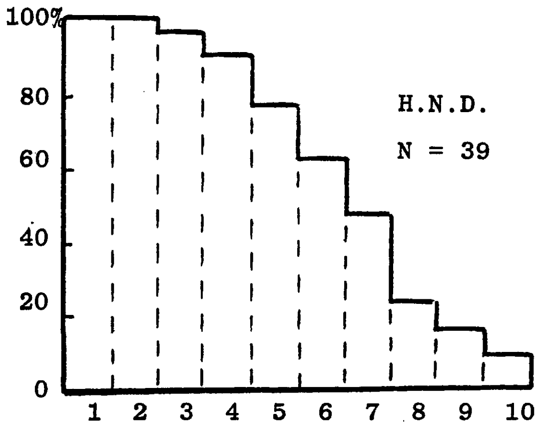
CONCEPT : FORCE

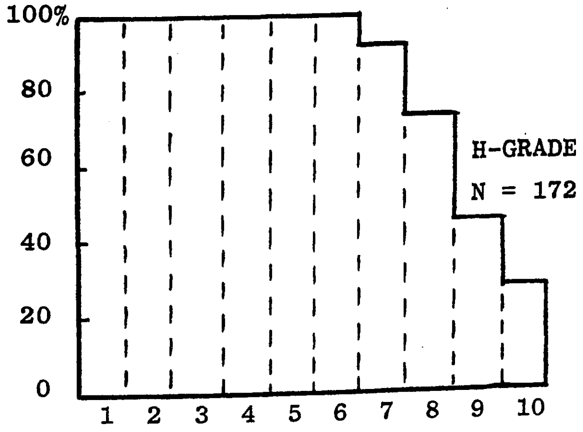
NUMBER OF 'VALID' BOXES = 10











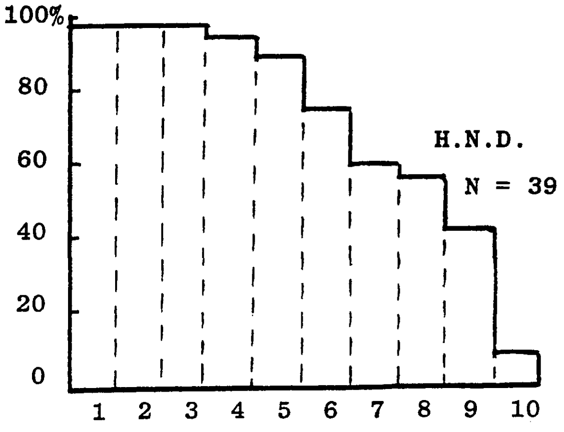


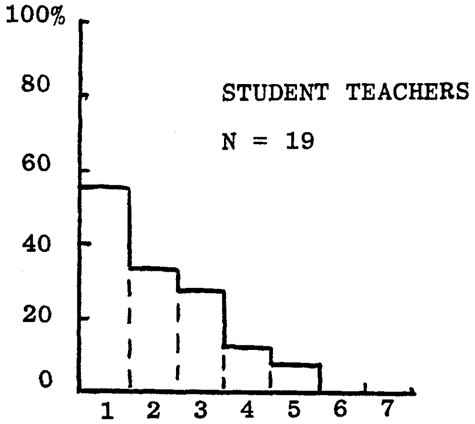
Table 43 - Analysis of response sheet for 'impulse'

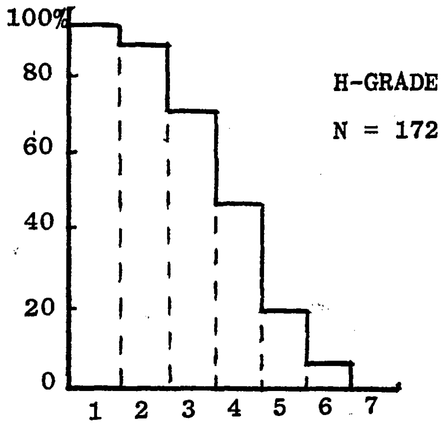
Number of 'valid' boxes = 7

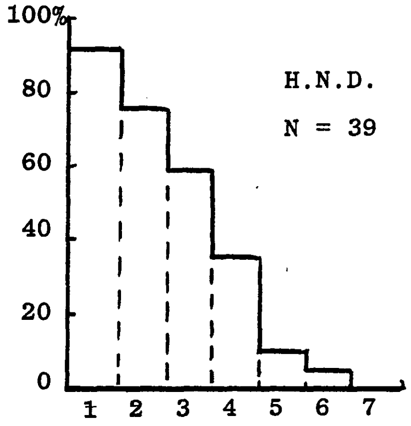
NUMBER OF BOXES		0	1	2	3	4	5	6	7	8	9	10	11	12	Av.	%
H-Grade pupils (N=172)	(A)	5	2	7	31	40	32	28	13	8	5	1			4.7	
	(B)	6	8	30	43	49	25	11							3.4	72
	(C)		96	92	74	49	21	6								
HND students (N=39)	(A)	3		1	6	10	12	5	1						4.3	
	(B)	4	6	7	9	10	2	1							2.6	60
	(C)		90	74	56	33	8	3								
B.Sc. students (N=34)	(A)	1	1	1	4	12	4	7	3	1					4.5	
	(B)	1	1	2	14	8	2	6							3.7	82
	(C)		97	94	88	47	24	18								
Student teachers (N=19)	(A)	7	3	3	4		1	1							1.7	
	(B)	9	4	1	3	1	1								1.3	76
	(C)		53	32	26	11	5									
Teachers (N=11)	(A)	1			1	2	2	2	2	1					5.0	
	(B)	1			1	2	5	1	1						4.5	90
	(C)		91	91	91	82	64	18	9							

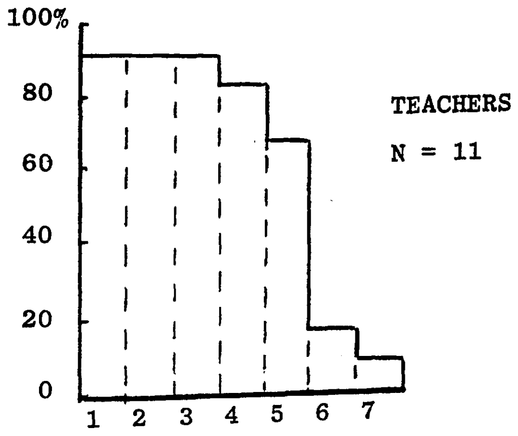
Figure 18 - Data from Table 43

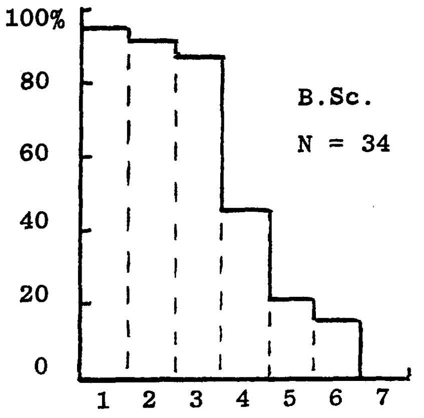
CONCEPT : IMPULSE NUMBER OF 'VALID' BOXES = 7











Conclusions from Part 2 of the material

(i) The defining equations for the concepts (e.g. $p = mv$, $E_k = \frac{1}{2}mv^2$, $E_p = mgh$) are correctly identified by almost all pupils.

(ii) The units for the concepts (e.g. J, N, Ns) are correctly identified by almost all pupils. (Some pupils even commented on the absence of kg m s^{-1} for '<u>momentum</u>')

(iii) The term 'scalar quantity' is not understood by many O-Grade pupils, and possibly not by many H-Grade pupils either.

(iv) The terms 'conserved' and/or 'collision' are likely to trigger the response '<u>momentum</u>', even where this is inappropriate, as in boxes 5, 14 or 25.

(v) Information conveyed in a diagram is probably not being fully processed by the pupil. For example, box 13 and box 22 were generally both included, because they had very similar diagrams, yet they referred to quite different concepts. Box 21, which showed a vector quantity being resolved into components, was seldom chosen except for '<u>force</u>', yet it applied equally to '<u>momentum</u>' and '<u>impulse</u>'.

(vi) Information conveyed in a graphical form will be found difficult to interpret by many pupils. For example, boxes 1, 8 and 23 were often connected to the wrong concept. (The same problem arose in Part 1).

(vii) The pupil's opinion of what is the most important feature of a given concept is likely to alter as the level of concept understanding increases. Thus the O-Grade pupil will generally pick the most basic defining equation. The B.Sc. student or the teacher, on the other hand, will choose a more general defining equation (e.g. $F = \frac{d(mv)}{dt}$) or some other general property of the concept. The unit, at this stage, is relatively unimportant.

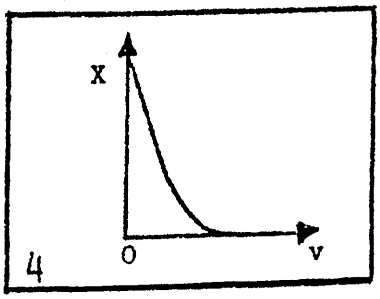
(viii) The teachers are most likely to include all the 'target' concepts in their choice, while the O-Grade pupils (or the student teachers) are least likely to include all of them. The B.Sc. students are generally about the same level of performance as the teachers. The HND students perform as well as the H-Grade pupils, distinctly poorer in overall performance than the teachers or B.Sc. students, but distinctly better than the O-Grade pupils or student teachers.

Possible revisions of Part 2 of the material

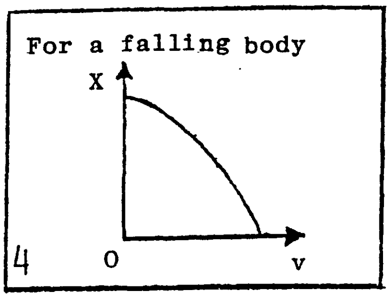
In chapter 5, we discussed the practical and theoretical requirements of a diagnostic test of conceptual understanding which could be used by a teacher in the classroom situation. It seemed to us that Part 2 of the test material offered the greatest potential for use as a diagnostic test. It was of a format suitable for group testing, was easily administered, took little time to complete and produced results which the teacher could interpret relatively easily. Most importantly, it had 'content validity', judging from the favourable comments of the teachers who had worked through the material. (One of them even suggested that all prospective teachers of physics should be required to sit such a test).

The format of Part 2 seemed quite suitable for a diagnostic test, but we thought we could improve the material by making some relatively minor changes in the contents of some of the boxes on the chart.

(a) The obvious error in the graph shown in box 4 should be corrected.



should be



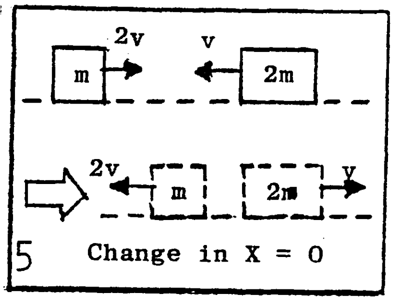
The phrase "For a falling body" may help to relate the graph to '<u>gravitational potential energy</u>'

(b) The statements in words (e.g. "Conserved ONLY in elastic collisions") had triggered off inappropriate responses (e.g. '<u>momentum</u>'). We could get round this problem if we replaced the word statement by a diagram which conveyed the same information. For example:

Conserved ONLY in elastic collisions

5

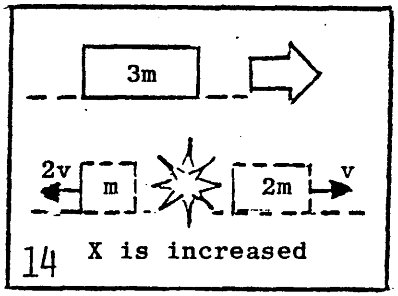
could be replaced by



Increased in an explosive collision

14

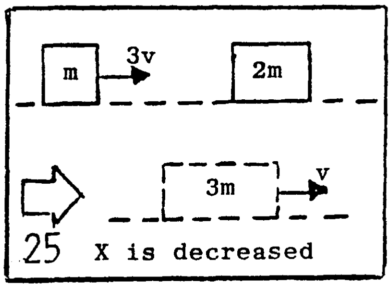
could be replaced by



Decreased in an inelastic collision

25

could be replaced by



(c) Statements involving units were correctly identified by almost all pupils, but this may indicate no more than rote learning. If we made a simple alteration, we could require <u>comprehension</u> rather than simple <u>recall</u>.
For example:

Measured in N

3

could be replaced by

X = 20 N

3

Measured in J

9

could be replaced by

X = 20 J

9

Measured in Ns

20

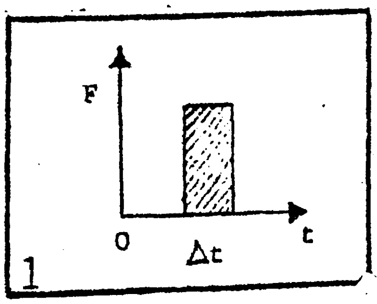
could be replaced by

X = 20 N s

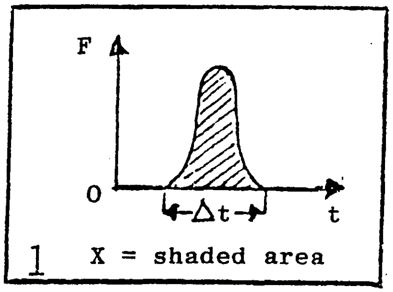
20

A box quoting the unit 'kg m s^{-1}' for '<u>momentum</u>' should also appear somewhere on the chart.

(d) Box 1 was included with '<u>momentum</u>', '<u>impulse</u>' and '<u>force</u>'. We could, perhaps, make this more specifically 'impulse' by drawing attention to the shaded area. Thus



could be replaced by



(We must, of course, still accept '<u>momentum</u>' for box 1)

(e) Box 11 and box 15 showed no significant difference in performance for any group. Only one of these would be required. We chose box 15.

(f) We could now put the statement 'A vector quantity' into box 11 to balance the statement 'A scalar quantity', which appeared in box 7.

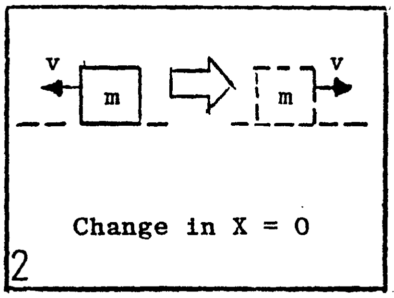
(g) Boxes 6, 12 and 24 contained alternative statements of Newton II. While the results showed that the O-Grade pupils preferred 'F = ma' to '$F = \frac{d(mv)}{dt}$', the difference was barely significant. We suspected that the unintentional clue of the letter 'F' appearing in all three boxes had distorted the results for these three boxes. The O-Grade pupils recognised 'F = ma' applied to '<u>force</u>' and, since the other two boxes also had an 'F' in them, they must also apply to '<u>force</u>'. We decided, therefore, to make the following changes:

$F = ma$ 6	would be replaced by	**For a falling body** $X = mg$ 6

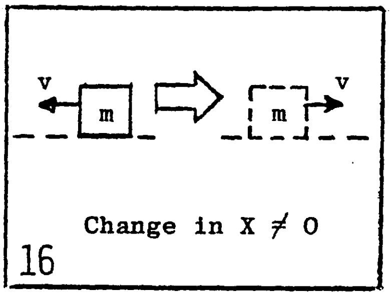
(In Part 1, '<u>weight</u>' was not a commonly used term. We are checking here if pupils recognise 'mg' as a force.)

$F = \frac{d(mv)}{dt}$ 12	would be replaced by	$X = \frac{d(mv)}{dt}$ 12

(h) We suspected that pupils did not recognise '<u>momentum</u>' as a vector quantity. We anticipated that a large number of pupils could choose the box containing the statement 'A vector quantity' and yet not recognise an example of a vector quantity. We therefore left box 21 as it was, but added two more boxes as follows:

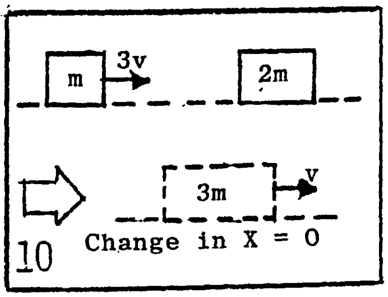


and

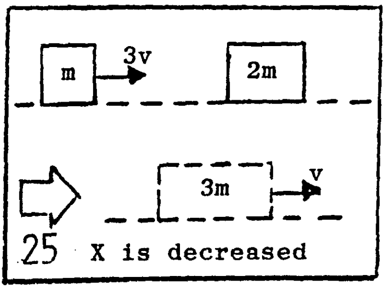


If the pupil really understands what a vector quantity is, then box 2 should be included with '<u>kinetic energy</u>' and box 16 should be included with '<u>momentum</u>'.

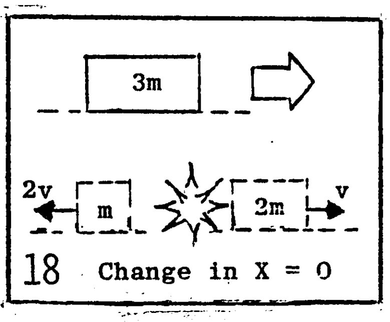
(i) We had to remove '$E_k = \frac{1}{2} mv^2$' from box 2 and '$p = mv$' from box 16 to get space for the above two boxes. We felt justified in doing this at this stage, but we realised that the basic defining equations would normally be included in a diagnostic test of concept understanding. We also removed '$E_p = mgh$' from box 10, and replaced it with a diagram of an inelastic collision.

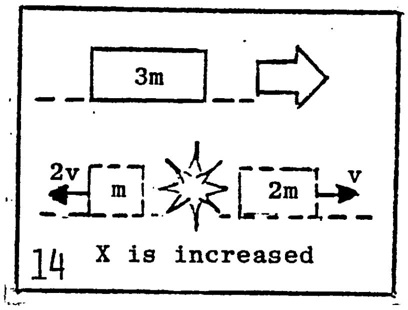


which is very similar to box 25



(j) Finally we replaced box 18, which contained the statement "Conserved in ALL collisions" by a diagram, which was identical to the diagram in box 14. Only the wording was different, so making the discrimination quite fine.





The revised version of the whole chart is given in Figure 18.

We were now in a position to conduct a further field trial with pupils. This was carried out, as will be described in the next chapter, in twenty selected schools throughout Scotland. However, before trying out the revised chart on pupils, we decided to try it out on teachers.

We had been impressed, while processing the results in Part 2,to note the remarkable unanimity that existed among the eleven teachers who worked through the test material. Recalling a statement made by Markle and Tiemann (11)

"The student who is learning the discipline masters it to the extent that he perceives the world in the same way that the subject matter expert does",

We decided to check what the 'subject-matter experts' saw in our revised concept chart. We therefore sent copies of the revised chart to some 30 of our colleagues, many of whom had been involved in the earlier teacher

Figure 18 - Revised chart for Part 2 of test material

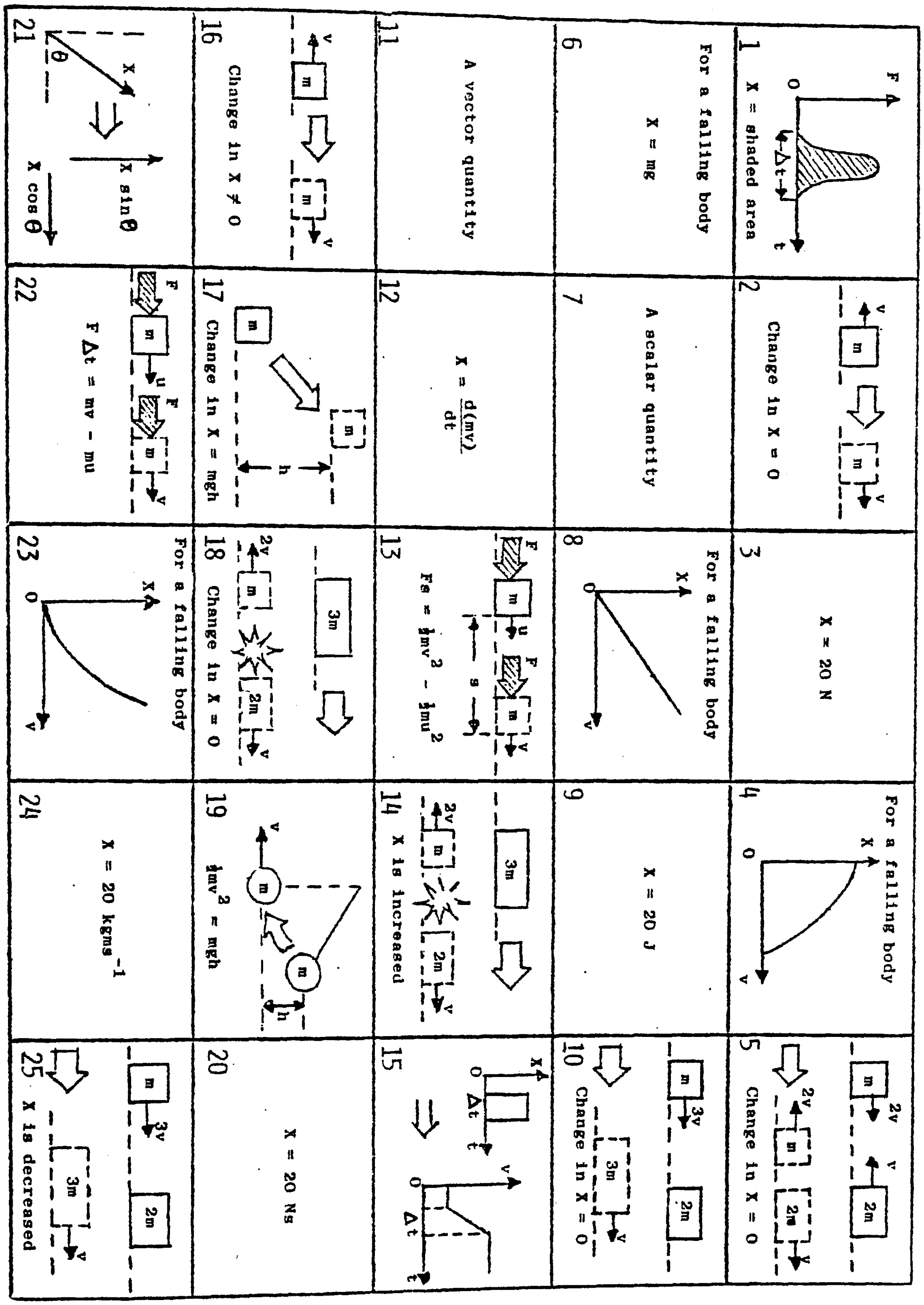


CHART A

questionnaire, described in chapter 2. We asked them to validate the material for us by completing a sample report pro forma.

A copy of the material as sent to the teachers is given in Appendix I. We will discuss the results and comments which came back from the teachers in the next chapter.

CHAPTER 7 - THE 1980-81 FIELD TRIAL

Introduction.

The test material described in chapters 5 and 6 appeared to have some potential as a diagnostic test of concept understanding. In this chapter, we will describe how a revised form of the test material was trialled in twenty selected schools throughout Scotland during the session 1980-81.

The revision of the test material

At the end of the last chapter, we described how the 5 x 5 chart used in Part 2 of the test material was modified, and how the modified version was validated by asking some 30 experienced teachers of physics to select, for each concept, the relevant boxes from the revised chart. We now discuss the results obtained from the teachers.

Three major points emerged from a study of the teachers' responses to the revised chart.

(1) For each of the five concepts involved, there was a spread of responses, with as many as 17 different boxes being chosen for 'momentum', and 22 different boxes for 'force'. In spite of this wide spread of responses, there was, as we had anticipated, a very clear consensus opinion as to what were the most relevant boxes.

Table 44 gives a summary of the teachers' responses to all 25 boxes. In Table 45, we show only the boxes which, by consensus opinion, are the most relevant boxes for each concept - what we might call the 'ideal choice'.

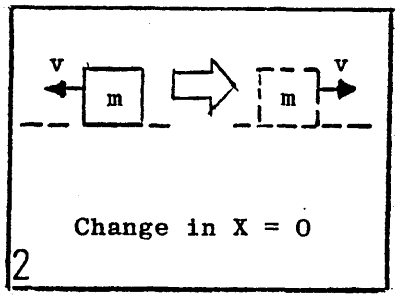
Table 44 - Responses of 29 teachers to chart A

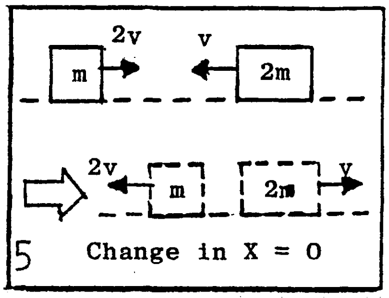
BOX NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
MOMENTUM	22	4	0	0	29	0	0	28	0	28	29	9	1	1	7	24	0	27	0	16	26	25	0	28	2
KINETIC ENERGY	0	25	0	1	24	0	29	0	29	2	0	0	24	28	1	2	0	1	27	0	0	1	29	0	29
POTENTIAL ENERGY	0	7	0	24	7	3	27	0	27	8	0	0	0	0	0	0	29	8	28	1	0	0	0	0	0
FORCE	11	2	29	0	3	29	1	0	0	1	28	28	16	2	24	4	1	1	1	3	29	11	1	1	1
IMPULSE	29	3	0	0	2	0	0	2	0	2	28	4	2	2	5	4	0	2	1	29	20	27	2	15	1

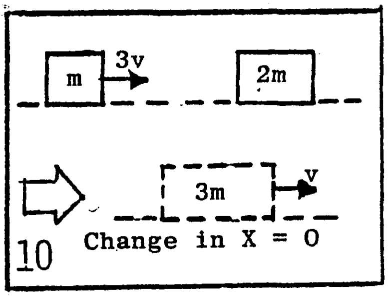
Table 45 - 'Ideal choice' of boxes for each concept

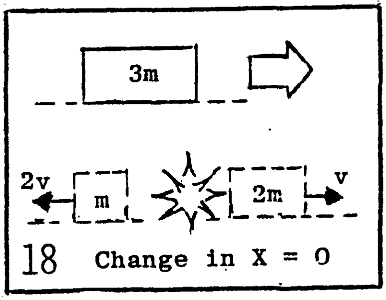
CONCEPT	BOX NUMBERS
MOMENTUM	1, 5, 8, 10, 11, 16, 18, 21, 22, 24
KINETIC ENERGY	2, 5, 7, 9, 13, 14, 19, 23, 25
POTENTIAL ENERGY	4, 7, 9, 17, 19
FORCE	3, 6, 11, 12, 15, 21
IMPULSE	1, 11, 20, 21, 22, 24

(2) It would be wrong to assume, from the wide spread of response, that the teachers were making frivolous choices. In all cases, there was clear evidence from the teachers' verbal and written comments about their responses, that they could justify these responses. For example, boxes 2, 5, 10 and 18 could refer to gravitational potential energy, since the diagram in each case shows there has been no vertical displacement of the masses.

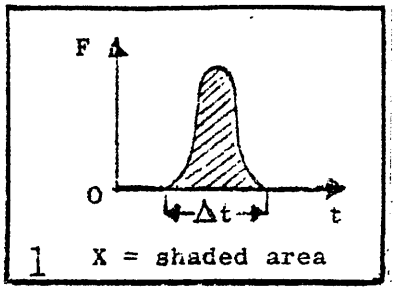


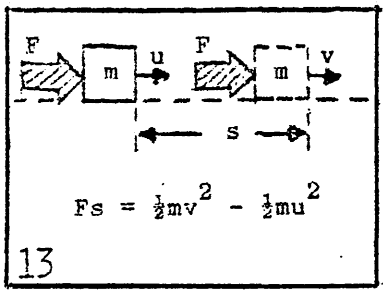


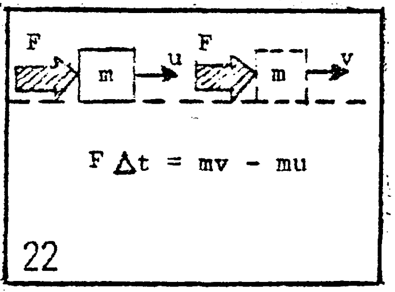




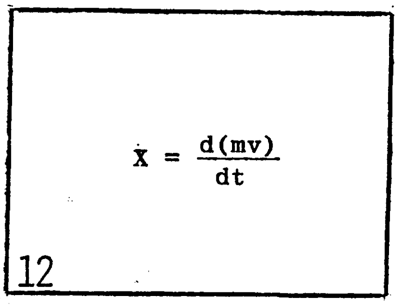
In some cases, the teachers admitted that they could only justify their choices by considering some, but not all, the information given in a particular box, or by interpreting the information in a specific, and very limited, way. For example, the appearance of the letter 'F' in boxes 1, 13 and 22 could justify including these boxes under the heading of 'force'.

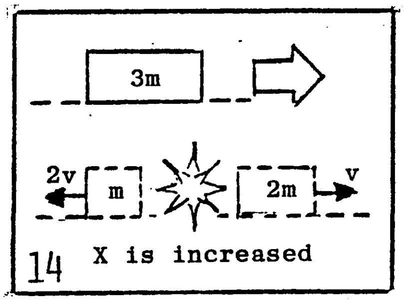






Box 12 refers to the rate of change of momentum, and therefore can justifiably be included under '<u>momentum</u>' while, in box 14, the <u>magnitude</u> of the momentum of the mass m (or the mass 2m) is increased by the explosive interaction, so it also could be included under '<u>momentum</u>'.



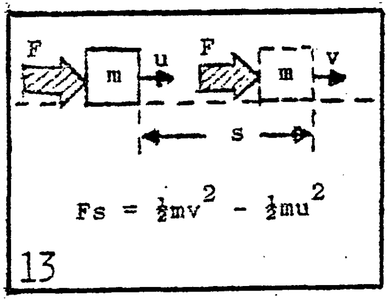


(3) Several teachers commented that they had some difficulty in interpreting the instructions. To quote one teacher:

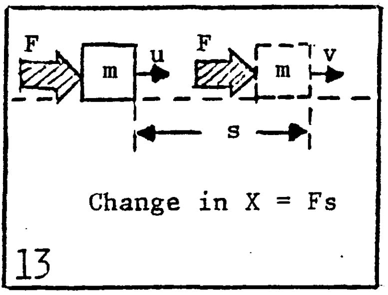
> "Perhaps one of the problems of showing teachers these tests is that we read too much into them. I certainly find it difficult to understand exactly what is wanted ..... I find, for example, that in instruction 2 you ask that we give the number of all the boxes which contain "<u>some information about</u>" the quantity and in response sheet 1 you ask that we give the number of all the boxes which "you think refer to" the quantity.
>
> I find these instructions incredibly difficult to interpret and therefore I am really not sure what to do. For example, do you mean that we include the boxes in which any of the quantities are used

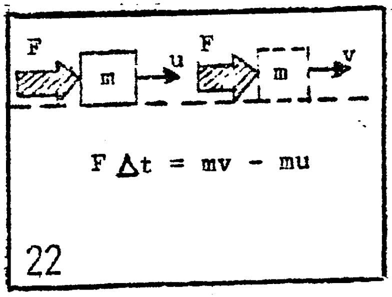
> directly, or indirectly, or mentioned specifically, or implied, or what? If what is intended is that the pupil is asked to fill in the numbers of all the boxes on the chart <u>in which the letter X refers to that quantity</u>, then there are five mistakes in the chart. I have corrected these and circled them in yellow. This is, I suspect, what is wanted and so, rather than give what seems to me to be a meaningless list of box numbers, I have interpreted your list to mean 'Give the numbers of the boxes in which X refers to, or could refer to, that quantity' "

The five errors referred to on the chart were boxes 7, 11, 13, 19 and 23 in which there was no specific mention of the quantity X. In each case, we made an appropriate alteration. For boxes 7, 11 and 19 we simply added 'X' to the given statement. Thus, in box 7, "A scalar quantity" became "X is a scalar quantity". In boxes 13 and 22, we also tried to make these boxes refer more specifically to '<u>kinetic energy</u>' and '<u>momentum</u>' respectively. Thus, for example:

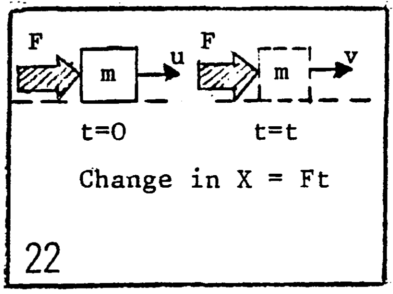


was changed to





was changed to



We would anticipate that '<u>force</u>' will no longer be a common response for these boxes.

The wording of the instructions was altered to refer more specifically to the 'quantity X', which now appeared in every box on the chart.

Having now revised, and, we thought, improved the chart, we started to put together a new draft of the test material, for a further field trial. The main purpose of this field trial would be a more extensive trial of the concept chart, but at the same time we could try out some other ideas.

We decided that, for this trial, we would use only H-Grade pupils, since parts of the material were unsuitable for O-Grade pupils. We also decided that all the pupils would sit the same test. There would be three parts, A, B and C.

Part A would consist of the revised concept chart and response sheet.

Part B would be a simplified version of the technique used in the previous trial, where the pupil was given a series of nine statements.

Part C would be a first trial of the technique described in chapter 5 in which the pupil is asked to select, in order, the relevant concepts and principles required to solve a given problem.

In part B, we decided to allow each pupil to choose his own rate of progress through the material, using his 'confidence level' to govern this. All pupils would be given the same first statement (e.g. "The quantity X is proportional to the mass of a body") and, as before, would be asked to identify the quantity X and to indicate how confident he was about his identification. According to his 'confidence rating', the pupil would either be given some encouragement, if he said he had no real idea, or cautioned against jumping to conclusions, if he said he was sure after only one statement. All pupils would then proceed to the second statement, which, we thought, should involve the dimensions of the quantity X.

After responding to the second statement, the pupil would again indicate his 'confidence rating'. The option of "I have no real idea, so I have just made a guess" would no longer be required. If the pupil indicated he was sure he had correctly identified the quantity X, he would be given the chance to ask one more question about the quantity X. He could either ask a question of his own, or any one of the five suggested questions. The answer to each question is either YES or NO.

If, after responding to the second statement, the pupil indicated he wanted more information, he would be directed to a third statement about the quantity X. This, we thought, could be of the form "The quantity X is involved in solving the following problem", followed by a typical multiple-choice item. After responding to the third statement, the pupil would again indicate his confidence rating.

If, at this stage, the pupil is sure he has correctly identified the quantity X, he is asked to name it, give its defining equation and the units in which it is measured. He is finally asked for two more important facts about the quantity X.

If, after three statements about the quantity X, the pupil is still wanting more information, he is given the chance to ask one more question, as described above. Having chosen the question, the pupil finds the answers to all five questions on the next page. He is then asked, as described above, to name the quantity X, give its defining equation, its units, and two more important facts about the quantity X.

What we have just described may appear unduly complicated, but it is, in fact, relatively simple to work through. We found no evidence that any of the pupils had any difficulty in following the instructions.

There were three new ideas incorporated into Part B.

The first was the use of the statement "The quantity X is involved in solving the following problem". This, we thought, was a good way to focus the pupil's attention on the concepts involved in the problem without asking them to solve the problem. The amount of information the pupil gets from this about the quantity X will clearly depend on his ability to analyse the given problem.

The second innovation was allowing the pupil to ask a question. The five questions we supplied were not, of course, equally useful in identifying the quantity X. Three of them would tell the pupil nothing he did not already know. What we were looking for here was the ability to pick out the discriminating question, which would help to identify the quantity X. By giving the pupil the chance to frame his own question, we hoped to get some evidence of how discriminating he could be, given the restriction that the answer must be YES or NO.

This technique, we thought, could be put to good use in the classroom to help pupils improve their understanding of concepts, by a 'twenty questions' routine, in which the pupils are required to ask precisely framed questions which can only be answered yes or no. As White (12) has pointed out, "this technique necessarily involves the students in processing their knowledge .... (and) it is a powerful means of bringing learners to see relationships among elements of knowledge they already possess and in getting them to transform a collection of ill-formed propositions into a smaller number of crisp and accurate ones".

The third innovation was to require the pupil to name the quantity X, to give its 'formal' definition and to state two other important attributes apart from the units in which the concept is measured. We are checking here that the pupil has acquired what Klausmeier (10) has described as the 'formal' understanding of the concept.

In Part C, the pupil would be provided with another chart containing, say, 12 propositions (e.g. "impulse = rate of change of momentum") and four conventional extended-answer problems taken from previous H-Grade papers. As was described in chapter 5, the pupil would be required to select, in order, the correct sequence of propositions he would apply to solve each problem. The first problem would be done as a worked example to show what was required.

A copy of the revised test material as used in the 1980-81 trials appears in Appendix J. In the test booklet, sections A, B and C were printed on different coloured paper to identify them more clearly.

The selection of schools to be involved in the trial.

For the 1980-81 trial, we decided to use a representative sample of twenty secondary schools throughout Scotland. None of these schools had been used in any of the previous trials. The proportions of our sample reflected both the geographic distribution of the population and, using information provided by the Scottish Certificate of Education Examination Board, the relative distribution of city schools to non-city schools, Roman Catholic schools to non-denominational schools and independent or grant-aided schools to local authority schools.

Thus we had in our sample 7 schools from Strathclyde Region, 2 schools from Central Region, 4 schools from Lothian Region, 2 schools from Fife Region, 2 schools from Tayside Region, and 3 schools from Grampian Region. There were, in all, 7 city schools, 4 Roman Catholic schools and 1 independent school.

Having received official permission from the Director of Education in each Region to carry out the trial, we then sought the advice of the Region's Science Adviser as to which schools within his Region might be invited to take part in the trial. The Headteacher in each selected school was then sent a copy of the test booklet and asked if he would be willing to allow his school to participate in the trial.

At this stage, we were pleasantly surprised by the very positive response we got from the schools. One school did not reply at all but, in most other cases, we received a reply within a few days indicating that the school would be "very happy to cooperate". We took this as an indication that the teachers saw some intrinsic value in the test material. As one Principal Teacher of Physics put it: "This is an exercise in which we shall be pleased to participate".

We had asked that one H-Grade class in each school be given the test material. Several schools offered more than one class, and one school in particular asked that all their H-Grade pupils should be involved. We had to run-off additional copies of the test material to meet the demand.

The appropriate number of test booklets were then sent to each school and the test was administered by the school at a time convenient to them. In most cases, the testing was carried out during December 1980 - January 1981.

We anticipated the test would require one double period (i.e. 70-80 minutes) to complete, but several teachers commented, on returning the completed test booklets, that the less able pupils found this time allocation too short, and were therefore unable to complete Part C of the test material.

In all, 429 H-Grade pupils took part in the 1980-81 trials. The details are given in Table 46.

Table 46 - Number of pupils from each school.

School	A	B	C	D	E	F	G	H	I	J
No.of pupils	39	13	17	24	15	35	14	13	25	14

School	K	L	M	N	P	Q	R	S	T	U
No.of pupils	23	14	20	20	16	55	37	16	4	15

(The 4 pupils from school T were late additions to our original sample. One of our colleagues from the Science Education Research Group asked her class if anyone wanted to try the test. The four who volunteered did it at home in their own time).

The results of the 1980-81 trial

The results from Part A are summarised in Table 47 and in Figure 19. The 'ideal choice' of boxes, for each concept, is the combination of boxes chosen by consensus opinion of the teachers. For each concept, we have also shown 'other' boxes frequently chosen by the pupil.

Table 47 - Summary of Part A of Test Material

ACTUAL → ↓ PERCENTAGE

MOMENTUM		IDEAL CHOICE										TOTAL	AVERAGE	OTHERS		
		1	5	8	10	11	16	18	21	22	24			2	14	25
TEACHERS	29	22 / 76	29 / 100	28 / 96	28 / 96	29 / 100	24 / 83	27 / 93	26 / 90	25 / 86	28 / 96	266	9.2	4 / 14	1 / 3	2 / 7
PUPILS	429	52 / 12	407 / 95	174 / 40	401 / 93	361 / 84	216 / 50	312 / 73	130 / 30	144 / 33	333 / 78	2536	5.9	308 / 72	143 / 33	70 / 16

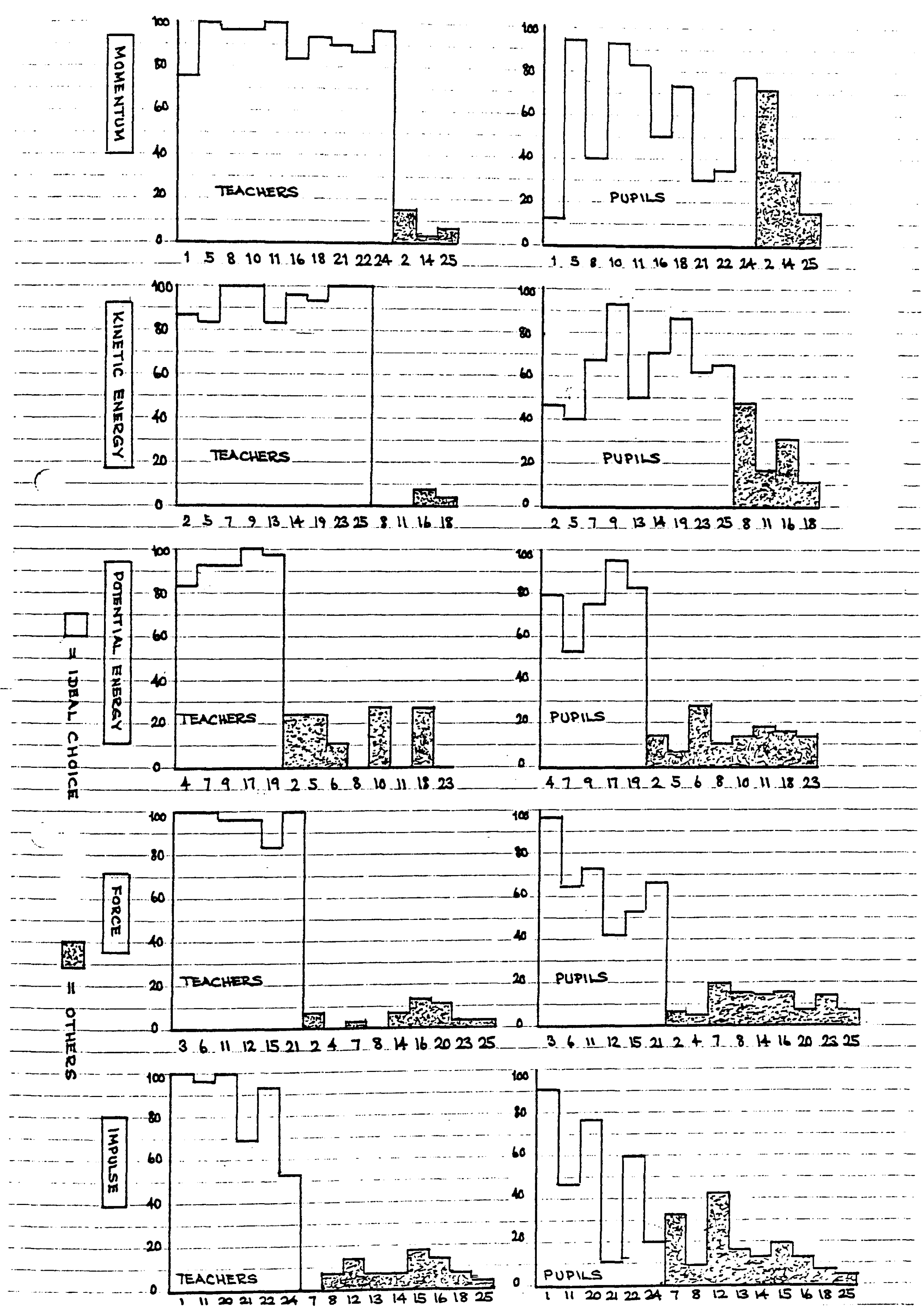
KINETIC ENERGY		IDEAL CHOICE									TOTAL	AVERAGE	OTHERS			
		2	5	7	9	13	14	19	23	25			8	11	16	18
TEACHERS	29	25 / 86	24 / 83	29 / 100	29 / 100	24 / 86	28 / 96	27 / 93	29 / 100	29 / 100	244	8.4	0 / 0	0 / 0	2 / 7	1 / 3
PUPILS	429	201 / 47	171 / 40	294 / 68	399 / 93	216 / 50	304 / 71	375 / 87	266 / 62	281 / 65	2488	5.8	205 / 48	75 / 17	133 / 31	47 / 11

POTENTIAL ENERGY		IDEAL CHOICE					TOTAL	AVERAGE	OTHERS							
		4	7	9	17	19			2	5	6	8	10	11	18	23
TEACHERS	29	24 / 83	27 / 93	27 / 93	29 / 100	28 / 96	135	4.7	7 / 24	7 / 24	3 / 10	0 / 0	8 / 28	0 / 0	8 / 28	0 / 0
PUPILS	429	340 / 79	233 / 54	327 / 76	410 / 95	352 / 82	1652	3.8	62 / 14	32 / 7	120 / 28	41 / 10	54 / 13	76 / 18	63 / 15	53 / 12

FORCE		IDEAL CHOICE						TOTAL	AVERAGE	OTHERS								
		3	6	11	12	15	21			2	4	7	8	14	16	20	23	25
TEACHERS	29	29 / 100	29 / 100	28 / 96	28 / 96	24 / 83	29 / 100	167	5.8	2 / 7	0 / 0	1 / 3	0 / 0	2 / 7	4 / 14	3 / 10	1 / 3	1 / 3
PUPILS	429	415 / 97	280 / 65	313 / 73	178 / 41	228 / 53	288 / 66	1702	4.0	32 / 7	23 / 5	84 / 20	60 / 14	56 / 13	62 / 14	35 / 8	58 / 13	34 / 3

IMPULSE		IDEAL CHOICE						TOTAL	AVERAGE	OTHERS								
		1	11	20	21	22	24			7	8	12	13	14	15	16	18	25
TEACHERS	29	29 / 100	28 / 96	29 / 100	20 / 69	27 / 93	15 / 52	148	5.1	0 / 0	2 / 7	4 / 14	2 / 7	2 / 7	5 / 17	4 / 14	2 / 7	1 / 3
PUPILS	429	389 / 91	200 / 47	331 / 77	47 / 11	252 / 59	86 / 20	1305	3.0	137 / 32	40 / 9	185 / 43	73 / 17	54 / 12	83 / 19	54 / 12	33 / 8	23 / 5

Figure 19 - Data from Table 47.

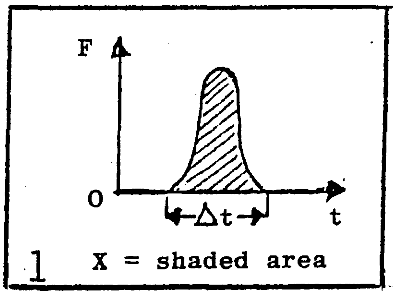


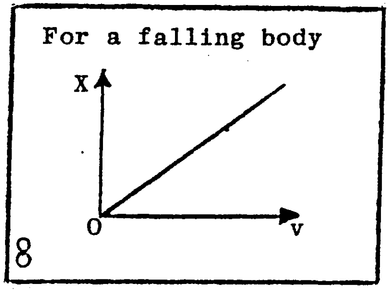
The complete results from Part A were given in Appendix K. Although there are variations in the pattern of responses for the different schools, these variations are more likely to be attributable to different methods of teaching than to any basic difference in ability. In terms of the number of 'valid' boxes included in their responses, no school was consistently better or consistently poorer than any other. There was no significant difference between the responses for school Q, in which all the H-Grade pupils were tested, and the responses for the whole test population.

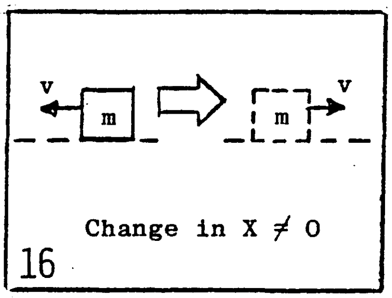
There were, however, significant differences in the overall pattern of responses between the pupils and the teachers. We will consider these differences for each concept in turn.

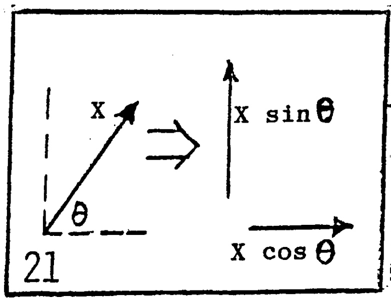
(1) Momentum

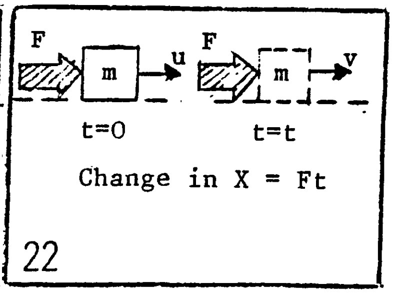
The following 'valid' boxes were selected by 50% or fewer of the pupils.



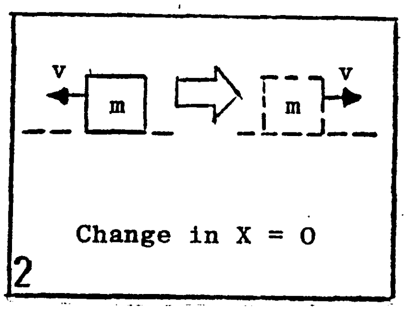






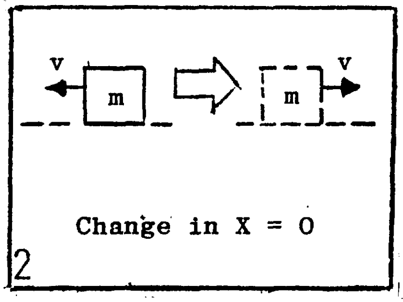


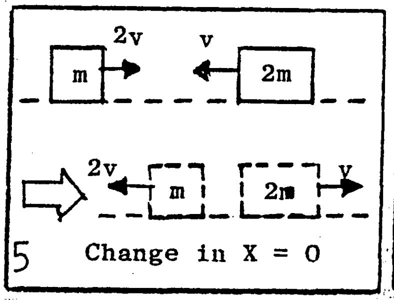
Box 2 was not a 'valid' response, but was chosen by 72% of the pupils. This result combined with the results from boxes 16 and 21, would tend to confirm that pupils do not understand the vector nature of '<u>momentum</u>'

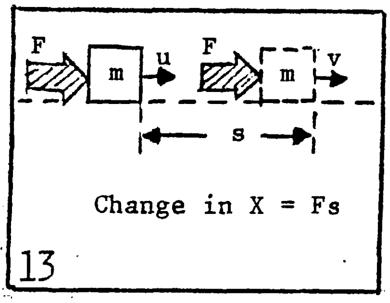


(2) <u>Kinetic energy</u>

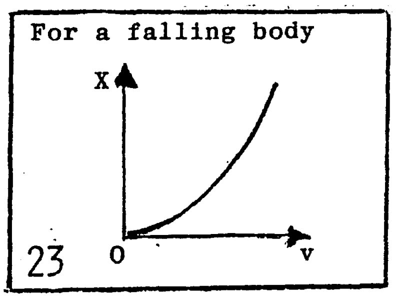
The following 'valid' choices were selected by 50% or fewer of the pupils.

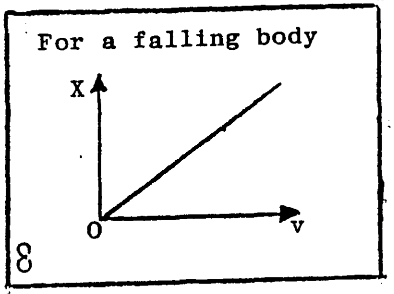






A significant number of pupils failed to include Box 23, while Box 8, which was not a 'valid' choice for '<u>kinetic energy</u>', was included by 48% of the pupils.





This suggests that the interpretation of sketch graphs is likely to be difficult for many of the pupils.

A significant number of pupils do not understand the term '<u>scalar quantity</u>' (Box 7).

(3) <u>Potential Energy</u>

The only significant differences for '<u>potential energy</u>' were in Box 7, which contained the term '<u>scalar quantity</u>', and in Box 6, which contained the expression 'X = mg'.

(4) <u>Force</u>

Box 12 was selected by only 41% of the pupils.

$$X = \frac{d(mv)}{dt}$$

12

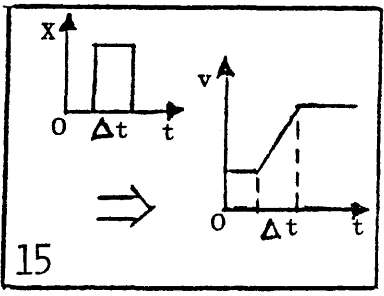
This would suggest that the calculus notation is <u>not</u> familiar to most H-Grade pupils, and that the result obtained in the 1979-80 trial was due to the letter 'F' providing an unintentional prompt.

A significant number of pupils failed to include the following 'valid' choices for '<u>force</u>'.

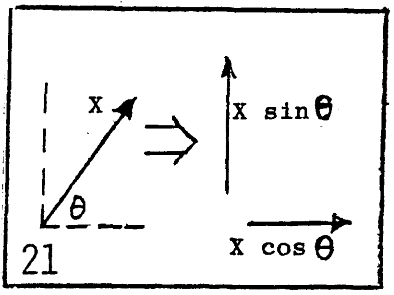
For a falling body

$X = mg$

6



15



21

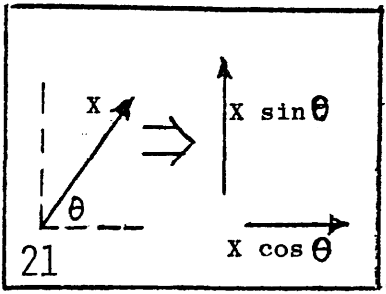
Box 21, however, was more often included with '<u>force</u>' than with either '<u>momentum</u>' or '<u>impulse</u>'. This suggests that the pupils are perhaps only <u>recalling</u> the diagram since they will have seen the diagram applied to '<u>force</u>' more frequently.

(5) Impulse

The following 'valid' boxes were included by fewer than 50% of the pupils.

X is a vector quantity

11



21

$X = 20 \text{ kg m s}^{-1}$

24

We would conclude that many pupils are not aware that 'impulse' is a vector quantity.

X is a scalar quantity

7

$X = \frac{d(mv)}{dt}$

12

A significant number of pupils include Box 7, indicating that they do not really understand the term 'scalar quantity'

A significant number of pupils include Box 12, perhaps because of the unfamiliar notation.

From the large number of irrelevant choices made for 'impulse', we must conclude that this concept is not so well understood as some of the other concepts. This may be due to the fact that the pupils will have had least experience of this concept.

We now consider the results from Part B of the test material.

Table 48 gives a summary of the results from page 5 of the test booklet. On this page, the pupils were given the first statement about the quantity X ("The quantity X is proportional to the mass of the

body".) The following responses were considered 'valid' responses:
'momentum', 'kinetic energy', 'potential energy' 'weight' and 'density'.

As in the 1979-80 trial, 'force' and 'impulse' were not accepted as 'valid' responses to the given statement.

Other responses included 'acceleration', 'velocity' and 'energy'.

Table 48 - Summary of results from page 5 of test booklet

Valid responses		Other responses		Confidence rating
momentum	= 68%	force	= 45%	1 = 2%
kinetic energy	= 59%	impulse	= 9%	2 = 15%
potential energy	= 53%	acceleration	= 7%	3 = 49%
weight	= 26%	other	= 15%	4 = 21%
density	= 12%			5 = 12%

The average number of responses is 3 per pupil, and, of those, 74% are 'valid' responses. The most common 'confidence' rating is "I think it is .... but I would like more information."

On page 8 of the test booklet, the pupils were given the second statement about the quantity X. Table 49 gives a summary of the results from page 8.

Table 49 - Summary of results from page 8 of test booklet

Valid responses		Other responses		Confidence rating
kinetic energy	= 55%	momentum	= 16%	1 = 24%
potential energy	= 22%	force	= 8%	2 = 34%
energy	= 6%	impulse	= 2%	3 = 32%
work done	= 4%			4 = 10%

The average number of responses has now fallen to about 1 per pupil, and the percentage of 'valid' responses is unchanged. Although '<u>kinetic energy</u>' and '<u>potential energy</u>' are equally 'valid', only a small minority of pupils offered both these responses.

The most common 'confidence rating' is still "I think it is .... but I would like more information", but there is a distinct swing towards "I am sure it must be ....."

<u>Table 50</u> gives a summary of the results from page 9 of the test booklet. Here the pupils were given a third statement about the quantity X. Over 40% of the pupils chose to omit page 9 by indicating a high 'confidence rating' at page 8.

<u>Table 50 - Summary of results from page 9 of test booklet</u>

<u>Valid responses</u>		<u>Other responses</u>		<u>Confidence rating</u>	
kinetic energy	= 58%	momentum	= 5%	1	= 19%
potential energy	= 26%	force	= 7%	2	= 42%
energy	= 4%	other	= 10%	3	= 31%
work done	= 3%			4	= 8%

The average number of responses is about 1 per pupil, but the percentage of 'valid' responses has risen to 81%.

Very few pupils gave <u>both</u> '<u>kinetic energy</u>' and '<u>potential energy</u>'. '<u>Work done</u>' was accepted as a 'valid' response even though it appeared in the stem of the multiple-choice question on page 9.

The most common 'confidence rating' is still "I think it is ..... but I would like more information".

On page 10 of the test booklet, the pupils were allowed to choose one of five given questions or ask a question of their own. On page 11, the pupils were asked to identify the quantity X, give its equation, its units, and two other important facts about the quantity X. The same information was also required on page 12, but no pupil would do both these pages.

The five questions on page 10 produced the following spread of choices.

(1)	Can the quantity X by resolved into components?	6%
(2)	Is the quantity X conserved in elastic collisions?	26%
(3)	Is the quantity X conserved in inelastic collisions?	24%
(4)	Is the quantity X measured in J ?	24%
(5)	Is the quantity X possessed by falling bodies?	17%

At this stage, the pupil will hopefully be aware that '<u>kinetic energy</u>' and '<u>potential energy</u>' are equally plausible, and the problem is to select a question that will discriminate between these two concepts. Although we intended question 3 to be such a question, it could be argued that this assumes the inelastic collision involves no change in the vertical displacement. In which case, none of the given five questions will clearly discriminate between the quantities, and the pupil must phrase a suitable question of his own.

It is clear from the results that few pupils argued in this way. The majority of pupils had decided that the quantity X was '<u>kinetic energy</u>', and chose a question which, in their view, confirmed their choice. This was clear from the type of question they chose to ask (e.g. Is the quantity X kinetic energy?")

Table 51 gives a summary of the results from page 11 of the test booklet. The results from page 12 are given in Table 52.

Table 51 - Summary of results from page 11 of the test booklet

Quantity X

Momentum = 3%
Kinetic energy = 78%
Potential energy = 10%
Energy = 3%
Force = 1%
Other = 3%

Correct equation - 90%

Correct units - 91%

Two other facts - 30%

One other fact - 24%

No facts - 42%

Table 52 - Summary of results from page 12 of the test booklet

Quantity X

Momentum = 2%
Kinetic energy = 63%
Potential energy = 24%
Energy = 2%
Force = 3%

Correct equation - 95%

Correct units - 92%

Two other facts - 24%

One other fact - 27%

No facts - 43%

We should explain that the defining equation, units and other important facts had to relate to whatever concept the pupil had identified as the quantity X.

We were surprised to note that many pupils had great difficulty in writing down the other important facts. A common answer was

> "Is conserved in elastic collisions
> Is not conserved in inelestic collisions"

A more detailed analysis of the results from Part B of the test material is given in Appendix L.

We now consider the results from Part C of the test material. (For convenience, the chart C is reproduced here)

work = force x distance 1	momentum = mass x velocity 2	component of weight down slope = mg sin θ 3	impulse = change in momentum 4
average speed = $\frac{\text{distance}}{\text{time}}$ 5	force = mass x acceleration 6	acceleration = $\frac{\text{change in speed}}{\text{time}}$ 7	loss in kinetic energy = work done against resistance 8
gravitational potential energy = mgh 9	impulse = force x time 10	kinetic energy = $\frac{1}{2}mv^2$ 11	in any interaction total change in momentum = 0 12

CHART C

When the completed test booklets were returned, several teachers indicated that the pupils had not had enough time to complete all the material. We therefore anticipated that Part C would not be attempted by many pupils. In fact 81% of the pupils completed all of Part C, and 94% of them attempted part of it.

The first problem on page 14 was set out as a worked example to illustrate the method. This appeared to be sufficient explanation for the pupils to understand what they were required to do.

The second problem on page 14 was chosen as a straightforward application of the principle "loss in kinetic energy = work done against resistance".

59% of pupils succeeded in choosing the correct sequence of boxes (i.e. 9, 11, 8, 1) or enough to show they understood the method (e.g. 9, 11, 8 or 9, 8 1) If they omitted the vital box '8', they were given no credit. Thus (9, 11, 1) was not an acceptable answer.

Pupils who recorded only (9, 11) were assumed to have no real idea how to solve the problem. A pupil who recorded only (8) or (11, 8) <u>may</u> understand how to solve the problem, but has not given enough for us to be sure he can solve it.

The most common error was to try to involve box 3 in some way (e.g. 9, 3, 6 or 3, 7, 6). Various combinations of boxes 5, 6 and 7 were also common (e.g. 5, 7, 6 or 7, 6, or 5, 7, 3, 6). It is clear, from such answers, that many pupils had not understood the problem.

The third problem, on page 15, was in three parts. This caused some confusion, since some pupils assumed they had to write down, in parts (b) and (c), the numbers of the boxes they had used in part (a). Also, in part (b) box 5 is used twice, once for the trolley and once for the tray. Some pupils were confused by this.

The correct sequence of boxes would be:

(a) 2 12 2 (b) 5 (c) 2 4 10

66% of the pupils gave the correct sequence for part (a), 63% gave (5) or (5, 5) in part (b) but only 40% gave the (4, 10) combination which was considered essential for part (c).

Part (c) of this problem can be solved using boxes 7 and 6, if we calculate the acceleration of the tray, and the force necessary to produce this acceleration. If we include the response (7, 6) in part (c), then the percentage of pupils answering correctly rises to 52%.

Many pupils thought it necessary, in this problem, to annotate their answer with an explanation of why they had put down certain box numbers. This may, indicate that not every problem lends itself to this technique of just stating the proposition to be applied. In some problems, more specific details will be required.

We noted that many pupils worked out their answer on paper, and then referred to the chart to select the appropriate box numbers. This may be their method of overcoming the problem of holding the entire sequence of steps in working memory.

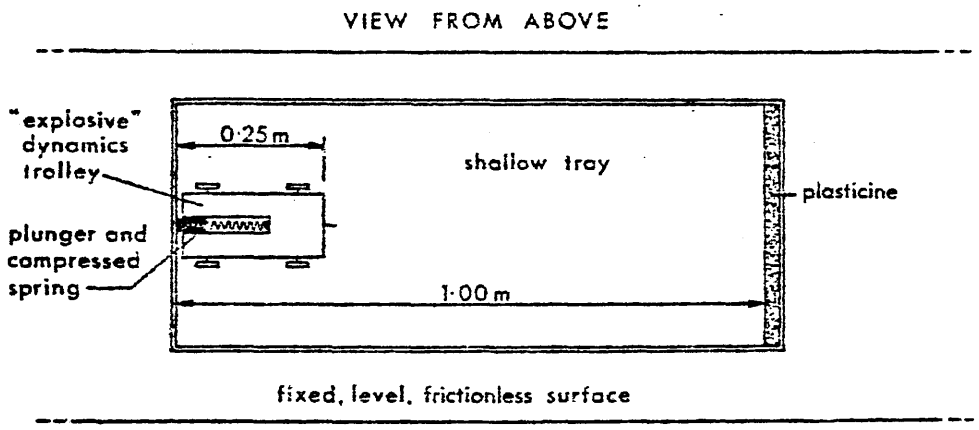
We also noted, with incomplete answers, that the pupil seemed to know how to start and/or how to end the sequence. Their problem was to link the start of the sequence to the end.

Sometimes the pupil was all too clearly aware of the difficulties, as the following example shows:

PAGE 15

PROBLEM 3 (1980 H-Grade Physics, Paper 2, Q2)

An "explosive" dynamics trolley of mass 1 kg is placed in a shallow tray of mass 10 kg which rests on a fixed, level, frictionless surface.



When the compressed spring is released, the plunger hits the wall of the shallow tray causing the trolley to move to the right at a speed of 0.50 m s^{-1} relative to the fixed surface. The tray moves to the left. When the trolley strikes the opposite wall of the tray, which is covered with plasticine, the whole system comes to rest again.

(a) Calculate the velocity with which the tray moves to the left.

Know mass, velocity
$v = 0$

(b) Calculate the distance which the tray moves before coming to rest.

want distance

1 : 5

(c) The time for which the plunger is in contact with the wall of the tray is 0.02 s. Calculate the average force exerted by the plunger on the wall of the tray.

If I could find the time I would use $a = \frac{v_2 - v_1}{t}$ $F = ma$ $W.D = fs$

SOLUTION TO PROBLEM 3 (a) 12 2 (b) 7 6 1 (c) 2 4 10

Got very confused

But I cant find time

In the fourth problem, on page 16, it was clear that most pupils appreciated that the first step was to calculate the speed of the trolley before it hit the stretched elastic band. Thus 63% of the answers started with box 5. Unfortunately only 10% gave the correct continuation of the sequence (ie. 5, 11, 8, 1). Most thought that the sequence was (5, 7, 6), which is wrong because it assumes a constant force.

The expected sequence for part (b) of this problem was (2, 4, 10) but an alternative sequence (6, 7) was also frequently used. Accepting either of these, 41% of the pupils were able to do part (b).

The technique used in Part C of the test material was being tried for the first time and has proved reasonably successful. The pupils were able to use the technique without obvious difficulties.(except where a given proposition was used more than once in the same problem or part of a problem). It showed that most pupils could link three or four propositions together in the correct sequence to solve a given problem and it identified both pupils who were using the wrong sequence and pupils who had only part of the sequence. To get the most benefit from using this technique, it would be necessary for the teacher to monitor each pupil's responses and, as necessary, to discuss incorrect and/or partially correct sequences with the pupil. From the pupil's point of view, there is just as much thought required to write down the sequence of propositions as to complete the problem. The teacher, however, can get a clearer picture of what each pupil is thinking from such a sequence. By concentrating the pupil's attention on the concepts and principles involved in any given problem, we think the technique could improve a pupil's problem solving ability, and at the same time, improve his understanding of the concepts and principles involved.

In theory, there is no reason why the scoring of a pupil's response could not be done by computer. The pupil's score would be made up of two parts:

(a) a 'relevance' score and (b) a 'sequence' score.

The 'relevance' score would be an index which measures the pupil's ability to select the relevant boxes from the chart. It could be computed as

$$\text{'Relevance' score} = \frac{\text{Number of 'relevant' boxes chosen}}{\text{Number of possible 'relevant boxes}} - \frac{\text{Number of 'irrelevant' boxes chosen}}{\text{Total number of boxes chosen}}$$

This index would vary between +1 (only 'relevant' boxes chosen) and -1 (only 'irrelevant' boxes chosen)

To calculate the 'sequence' score, we must first get round the problem of missing characters' (e.g. if the agreed correct sequence is 5841 but the pupil's response is 841). We simply remove from the agreed correct sequence any characters not included in the pupil's input (and possibly impose a penalty score of -1 for each deletion). We then have two sequences which contain the same characters and we compare them directly. If we take all the possible sub-sequences of the pupil's sequence, we can score, say, +1 for each sub-sequence whose elements are ordered as in the correct sequence. For example, the sequence 5841 has sub-sequences 58, 84, 41, 584, 841. The maximum possible score for a sequence of four characters is thus 5. If the pupil's sequence was, say, 8541 then, we would score this as

85 - 0
54 - 1
41 - 1
854 - 0
541 - 1 Total = 3

If required, this 'sequence' score can be reduced to a figure between 0 and 1 by dividing by the number of sub-sequences.

A computer program has been written to do this, but we have not yet tried it out with real data. We see no practical reason, however, why it should not be possible to use the computer to score extended answer questions if we are agreed on the 'correct' answers.

CHAPTER 8 - CONCLUSIONS AND RECOMMENDATIONS

Introduction

In this final chapter, we will try to relate the results of our investigations to the theories of learning described in chapter 2, and will make some tentative conclusions about the pupils' understanding of concepts in mechanics. We will also consider some possible implications of such conclusions for the classroom teacher, and make some recommendations which, we hope, could lead to some general improvement in concept learning.

Relating the results to concept learning theory

We start by reviewing some of the more important ideas of concept learning.

Klausmeier et al (10) have described a model of conceptual learning and development which contains four stages or levels: (1) concrete level (2) identity level (3) classifactory level and (4) formal level. Only the classifactory level and the formal level are relevant to our investigation.

"Attaining a concept at the classifactory level involves generalising that two or more discriminably different stimuli are equivalent on some basis. At this level, subjects can reliably classify stimuli into classes, but may not be able to define the concept in terms of its relevant attributes ..... Attainment of the formal level of concept mastery requires that the subject be able to name the concept and define the concept in terms of its relevant attributes".

Markle and Tiemann (97) state that "to really understand a concept is to be able to generalise to all possible instances that might be presented and to be able to discriminate all possible non-instances, including those that bear a strong resemblance to the members of the class. These are the key behavours that distinguish an expert, such as a physicist, from non experts"

According to Markle and Tiemann (11), over-generalisation occurs when a non-example is classified as an example; under generalisation occurs when an example is classified as a non-example; and a misconception occurs when items are incorrectly classified on the basis of an irrelevant attribute.

The test material we devised for the investigation was intended to check that the pupil had attained at least the classifactory level of each concept. In the latter part of the material, the pupil was required to state explicitly the societally accepted defining attributes for a chosen concept, that is, to show his attainment of the concept at a formal level. We noted that a significant proportion of pupils were unable to give the 'defining equation' for their chosen concept. More importantly, perhaps, we noted an even greater proportion were unable to state two other important facts about their chosen concept. This could imply that by no means all pupils have attained the concept at a formal level, and are still operating at the classifactory level.

The 5 x 5 chart used in the 1979-80 trials checked that the pupils could recognise the 'defining equation' for each concept. The results showed that the majority of pupils, at all stages from O-Grade upwards, could correctly identify the 'defining equation' for each concept. From this we can only conclude that 'recognising' the defining equation is somehow easier than 'stating' the defining equation.

Classifying boxes on the chart as examples or non-examples of a given concept revealed some common cases of over-generalisation (e.g. any box containing the term 'collision' referred to 'momentum') and under-generalisation (e.g. "X is a scalar quantity" does not refer to 'kinetic energy') (There may also have been idiosyncratic examples of misconceptions, but we did not look especially for such examples.)

Two particular examples were very common:

(i) '<u>momentum</u>' was treated as a scalar quantity in boxes where the information was presented as a diagram (e.g. Box 2 on the chart)

(ii) '<u>force</u>' was the only vector quantity which was recognised as being resolvable into components (e.g. Box 21 on the chart).

Gagne (24 ,49), Ausubel (17) and Ausubel and Robinson (44) have described the conditions for the learning of what Gagne has called '<u>principles</u>' or '<u>rules</u>' and what Ausubel and Robinson have called '<u>propositions</u>'. According to Gagne, concept learning is prerequisite to learning rules, and rule learning is prerequisite to problem solving. According to Ausubel, meaningful learning, in contrast to rote learning, must be relatable to the knowledge one already has, and must be incorporated into one's existing cognitive structure.

The results we obtained from the pupil tests, described in chapter 4, and the field tests of the specially devised test material, described in chapters 6 and 7, would indicate that rote learning of concepts and principles is not uncommon, particularly at O-Grade. The attributes of the concept which were most frequently selected were also the attributes which could be rote learned (e.g. the defining equation, the units in which the concept was measured). The pupils could <u>state</u>, for example, that '<u>momentum</u>' was a vector quantity, but were frequently unable to <u>recognise</u> an instance of a vector quantity. Similarly, they were able to <u>state</u> that '<u>kinetic energy</u>' was conserved in an elastic collision, but were unable to <u>recognise</u> an instance of an elastic collision. There was some evidence that some diagrams may be rote learned (e.g. Box 21 for '<u>force</u>', Boxes 5, 10 and 18 for '<u>momentum</u>', Box 17 for '<u>potential energy</u>', and Boxes 1 and 22 for '<u>impulse</u>').

The likelihood of pupils giving 'rote learned' responses is much greater in some parts of the test material than in others. To obtain the most valid measure of concept understanding, we should therefore look at the parts of the test material which were least likely to be affected by 'rote learned' responses. One such part would be the sequence of nine statements about the quantity X. If we look at the number and the variety of the 'valid' responses given by each group, then we can see a marked increase in both the number and variety of 'valid' responses as we move from the O-Grade pupils to the B.Sc. students. The teachers give as many 'valid' responses as the B.Sc. students, but the variety of their responses is more limited. We would explain this in terms of everyday usage of the concepts. The teachers are less likely to suggest concepts such as '<u>moment of inertia</u>' or '<u>angular momentum</u>' because they are not using such concepts in their day to day teaching. In the same way, we would explain the very poor performance of the student teachers, who, in almost all cases, will not have used concepts in mechanics since they left school. In other words, concept understanding may be dependent on how recently the concept was learned and on how frequently the concept has been used. It would appear that concepts which were learned some time ago and have not been frequently used since they were first learned are no longer really understood. Conversely continued frequent use of a concept leads to an improved understanding of the concept, as evidenced by the significant increase in a pupil's performance between O-Grade and H-Grade.

The factors which affect the attainment of concepts and principles may be grouped into three categories:

(i) the characteristics of the learner
(ii) the characteristics of the learning situation
(iii) the characteristics of the concept.

Various students have shown that performance on concept attainment tasks improves with age. The results from our pupil tests, described in chapter 4, showed a highly significant improvement between O-Grade (S4) and H-Grade (S5). Similar improvement was evident in the 1979-80 and 1980-81 field trials. We would explain this improvement with age as a consequence of the pupil having developed a more highly elaborated cognitive structure and an improved ability to reason logically. There is no significant difference in performance between the O-Grade and H-Grade pupils on tasks which involve no more than rote-learning.

In our investigation, we did not attempt to control the learning situation in any way. We were interested only in trying to assess the level of concept understanding achieved. We noted minor variations in the pattern of responses between different schools but, since the overall differences were insignificant, we did not attempt to trace these differences back to some variation in the learning situation.

Klausmeier et al (10) have noted several aspects of the learning situation which affect concept mastery:
"One aspect is the type of information given. A rational set of both positive and negative instances, verbal cues concerning relevant attributes, the concept definition with prompting questions related to the definition, synonyms, and sentences using the concept names have all been shown to facilitate concept attainment. In general, providing a combination of these types of information is better than providing a single type. The amount of irrelevant information should be minimised. Concept instances should be presented simultaneously and ample time should be allowed for study".

These suggestions, together with the advice given by Johnstone regarding 'information overload' (see page 43), may help the classroom teacher when introducing new concepts and developing existing concepts.

Klausmeier et al (10) make the important point that the '<u>validity</u>' of a concept will affect the ease with which pupils can attain the concept". If experts disagree on the defining attributes of a concept, they will also disagree on which instances are examples of the concept and which are non-examples. Inconsistencies in the characteristics of examples given by experts make it difficult for the learner to infer common defining attributes for the concept".

By having the 5 x 5 chart 'validated' by a number of subject-matter experts, we were reasonably confident that we had correctly identified instances and non-instances of each concept. However, we did note some minor inconsistencies, particularly with the concepts of '<u>momentum</u>' and '<u>impulse</u>'. This may have had some effect on the pupils' responses, particularly with the concept of '<u>impulse</u>', for which we noted a large number of irrelevant responses were given by many pupils.

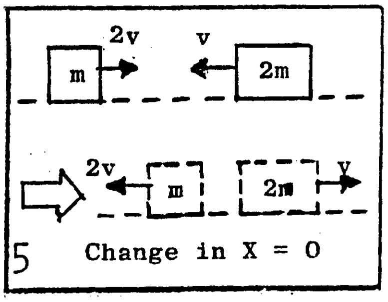
Klausmeier et al (10) also note that the number of relevant attributes will have an effect on the ease of concept learning. "Increasing the number of relevant attributes may have two effects: (a) the number of alternative hypotheses to be tested may increase, and (b) the number of hypotheses to be remembered increases. Both of these effects, of course, make concept learning more difficult". Johnstone (74) has also noted the difficulty for concept learning of providing too much information - particularly if such information is non-essential.

We noted that, of the five concepts tested, the concept for which the pupils' responses most closely matched the teachers' responses was '<u>gravitational potential energy</u>' for which the number of relevant instances provided on the chart was least. Conversely, the concept of '<u>momentum</u>', for which the number of relevant instances provided on the chart was greatest, wasthe one which showed perhaps the greatest variation between the pupils' responses and the teachers' responses. We would, however, be quite unjustified in assuming that this constitutes evidence of an inverse relationship between the level of concept understanding and the number of relevant boxes provided on the chart. Each separate box on the chart must be considered on its own merits. Some will be specific instances, others will be more general instances. For the pupil, some boxes will be easily identified as instances or non-instances, others will only be categorised with difficulty, if at all. The greater the number of separate instances to be categorised the greater likelihood there will be of variation between the pupils' responses and the teachers' responses.

Where we have found evidence of increased concept understanding, we have not been able to pinpoint whether the pupils' understanding of each specific concept has increased or whether his understanding of the interrelations between concepts has increased. We suspect that both have in fact increased by an extension and further elaboration of his existing cognitive structure. To this extent, we have found Ausubel's learning theory has provided an adequate explanation of our observed results.

In chapter 5, we discussed the need for a criterion-referenced concept attainment test, by means of which the classroom teacher could quickly and reliably assess the level of concept understanding of each pupil. Although the test material we devised was not intended to be a diagnostic test, we believe that it fulfils many, if not all, the basic requirements of such a test.

By noting certain omissions or particular inclusions, the teacher may quickly diagnose a pupil's failure to discriminate a given concept. Particular patterns or combinations of responses may imply particular misconceptions. The teacher can analyse the probable pattern of responses beforehand, and can prepare appropriate remedial teaching sequences to correct the more obvious errors. Errors which indicate over-generalisation or under-generalisation of a concept may be corrected by providing further examples and/or non-examples of the concept. The teacher may decide that, for a given concept, some boxes on the chart will be more relevant than others. Thus, for example. Box 5 on the chart may be considered essential for 'momentum', desirable for 'kinetic energy', insignificant for 'potential energy' and irrelevant for 'force' and 'impulse'.



By giving a relative weighting to all possible responses for each concept on a scale, say, from +2 (essential) to 0 (irrelevant) to -2 (clearly wrong), a pupil's pattern of responses may be converted into a crude numerical index which will reflect, to some degree, his level of understanding of the concept. Various refinements could be added to take account of specific patterns of responses, but the principle should be clear enough. If desired, a criterion level of performance could be included.

With the increased use of microcomputers in the classroom, there is no reason why the whole procedure could not be set up as a computer program. The computer, using its graphics facility, could present the various instances and non-instances of each concept on the VDU screen and, using the pupil's response at the keyboard at each stage, score the pupil's responses according to some pre-arranged scoring system. The computer could select an appropriate remedial sequence, if necessary, to bring the pupil up to the agreed criterion level of performance on that concept.

Implications for the classroom teacher

The results of our investigation have revealed, among other things, that:

(i) the pupil's ability to 'rote-learn' the defining equation for a given concept may give a false idea of his real understanding of the concept.

(ii) information conveyed in the form of a diagram may not be processed by many pupils.

(iii) information conveyed by a graph will be found difficult to interpret by many pupils.

(iv) the concept 'impulse' is not understood by many pupils.

(v) the vector nature of 'momentum' is not appreciated by many pupils.

These results have implications for the classroom teacher. For example, the teacher should not assume that because a pupil can recall an expression such as '$E_k = \frac{1}{2}mv^2$', the pupil understands the meaning of the expression.

Teachers should be aware that pupils do not always understand diagrams and sketch graphs. This may be because the diagram or sketch graph presents too much information for the pupil to assimilate, and the answer may be to keep such diagrams and sketch graphs as simple and uncluttered as possible.

Many teachers are already aware that pupils do not fully understand the concept '<u>impulse</u>' or the vector nature of '<u>momentum</u>'. They indicated this when they were asked to suggest likely areas of difficulty for an H-Grade pupil (see page 76).

Teachers can help their pupils to achieve real understanding of concepts in various ways. We would recommend the following teaching strategies which, we think, are likely to improve pupils' concept understanding.

(1) The learning outcomes of the teaching sequence should be clearly defined in terms of specific objectives which the pupil will be expected to attain and the minimum level of satisfactory performance. In other words, the criteria of successful learning should be evident both to the teacher, in terms of what must be taught, and to the pupil, in terms of what must be learned.

(2) The teacher should periodically check the progress of each pupil, and where necessary, modify the learning sequence. This requires some means of assessing the degree of attainment of specific concepts and principles, and of diagnosing the reason for a pupil's failure to attain a specific concept or principle.

(3) Since intellectual skills are learned hierarchically, the teaching sequence should take account of this, and should proceed from the level of conceptual understanding the pupil already has - his prior

knowledge - to higher levels of understanding in a sequence consistent with the hierarchy.

(4) Concept understanding requires the meaningful assimilation of the concept into the pupil's existing cognitive structure. In any one lesson, therefore, the teacher should check that the pupils have the necessary prerequisite knowledge, and should ensure that all pupils have achieved the desired additional knowledge. To encourage the pupils to process this additional knowledge into their long-term memory, the teacher should use a wide variety of techniques, such as analogies to other situations, discussion of everyday applications, experimental demonstrations and pupil practical work. A particularly useful technique is to give pupils the opportunity to verbalise their own understanding of the concept or principle involved.

(5) The teacher can help the pupils acquire a better grasp of a concept or principle by asking appropriate open-ended questions which involve the pupil in processing his knowledge of the concept or principle in a problem-solving situation. The teacher can also help concept understanding by giving the pupils numerous simple examples, which provide concrete instances of the concept or principle, as well as the formal precise definition.

(6) Concept understanding improves with use. Teachers should therefore give the pupils sufficient opportunity to practise using the concepts in a wide variety of contexts. At the initial stages of learning a particular concept, the teacher should ensure that irrelevant, distracting information is kept to a minimum but, as the level of understanding increases, the pupil should be required to discriminate between the relevant and irrelevant information in order to

improve his understanding of the concept, and its relationship to other concepts. In problem-solving situations, most emphasis should be placed on selecting the appropriate concept or principle.

(7) Since new knowledge is processed into long-term memory through the working memory, and since the working memory is of limited capacity, the teacher must guard against presenting too much information at any stage of the learning sequence. Presenting information in the form of diagrams or graphs should be minimised at the early stages of concept learning. On the other hand, diagrams and sketch graphs can be valuable 'chunking' devices to summarise information and can be very useful to the student who has already acquired a certain level of understanding of the concept. The use of diagrams and graphical methods of representing information should therefore be carefully phased into the learning sequence.

(8) Rote learning, as opposed to meaningful learning, of concepts and principles is not uncommon, particularly with younger pupils. Teachers should guard against implicitly encouraging rote learning by over-emphasising the recall of formal definitions, the ability to perform routine calculations and the importance of verbal knowledge. The teacher should take every opportunity to promote meaningful learning by oral and written questions and class discussion. The pupils should be given experience of problem-solving, and encouraged to think creatively.

Recommendations for further action

In the course of our investigation of the pupils' understanding of concepts in mechanics, we have devised three new techniques, all of which, we think, could be used by the classroom teacher in other areas of the syllabus.

We would recommend, therefore, that serious consideration be given to the development of concept attainment tests in all the major areas of the physics syllabus, at both O-Grade and H-Grade stages. Such tests should be criterion-referenced, in the sense that each pupil should be required to achieve a certain minimum level of performance. Such tests should be easily and quickly administered, and the results of such tests should be easily interpreted. Our chart of 25 numbered boxes and the associated response sheet could be used as a model for such a concept attainment test.

We would also recommend that teachers should devote more attention, in systematic problem solving, to the selection of the appropriate concepts and principles rather than to the mathematical manipulation of the resulting equations. To this end, we suggest that pupils should be given practice in selecting the appropriate propositions from a prepared list which may be presented, as we have done, in the form of a grid of numbered boxes.

Finally we would recommend that teachers prepare lists of statements, going from the general to the specific, for physics concepts in other areas of the syllabus, and then use these lists of statements in their day to day teaching to give pupils practice in what we consider is a very useful learning experience, since it enables the learner to match his choice of relevant concept at each stage with that of other pupils and with that of the teacher.

Certain problems still remain unresolved. We still cannot say for certain whether the significant increase in performance between O-Grade and H-Grade is due to increased knowledge of each concept or increased awareness of the inter-relationship between concepts. We still cannot say, with certainty, that an O-Grade pupil 'understands' the concept of, say, '<u>momentum</u>'. We still know very little about the nature of the pupils' misconceptions. We have no direct evidence of the extent to which the pupils' understanding of these concepts can be affected by the nature of the learning experiences and the teaching strategies employed. There is clearly still much research to be done in this field.

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LIST OF APPENDICES

THE UNIVERSITY OF GLASGOW

DEPARTMENT OF SCIENCE EDUCATION

TEACHER QUESTIONNAIRE ON MOMENTUM AND ENERGY CONCEPTS

INTRODUCTION

This is part of a larger, on-going, research project to investigate the development of concepts in physics in secondary school pupils. This part of the project is concerned only with the specific concepts of momentum, kinetic energy and (gravitational) potential energy. The purpose of this questionnaire is to sample the opinion of experienced teachers of physics on three specific points relating to these three concepts.

(a) What, in their opinion, is the importance of these concepts to the study of physics at school level (i.e. at O-Grade, at H-Grade and, possibly, at C.S.Y.S.)

(b) How, in their opinion, are these concepts dependent upon other, possibly more basic, concepts.

(c) What, in their opinion, are some of the reasons a given pupil may have difficulty in understanding these concepts.

The results of this questionnaire, together with similar information gathered from interviews with pupils, will be of assistance in the next stage of the research.

INSTRUCTIONS FOR THE COMPLETION OF THE QUESTIONNAIRE

There are 5 parts to this questionnaire.

(1) In part A, you are asked to write a few sentences for each concept in the space provided.

(2) In part B, you are asked to indicate your choice by putting a tick (✓) in the appropriate column.

(3) In part C, you are asked to put a tick (✓) and/or a figure (3, 4 or 5) and/or a letter (P, D or N) in the appropriate column.

(4) In part D, you are asked to indicate your choice by putting a tick (✓) in the appropriate column. In addition you may wish to add written comments in the space provided.

(5) In part E, you are asked to provide some statistical information. Completion of this section is wholly voluntary but it would be helpful if you provided as much information as possible.

PART A - The importance of the concepts

We are interested here in learning what, in your opinion, is the importance of each of the concepts of momentum, kinetic energy and gravitational potential energy to the study of physics at school level. The fact that all of these concepts appear more than once in the SCEEB Physics syllabus (e.g. B1, B2, B3, G2, J5, J6, K3 and N2) is not unimportant but, for the moment, we would ask that you put aside such considerations, and concentrate solely on why pupils studying physics should be introduced to such concepts. In other words, why are these important concepts in physics?
Could we teach physics without introducing these concepts?
What justification is there for including these concepts in a school physics course?

(a) Momentum

(b) Kinetic Energy

(c) (Gravitational) Potential Energy

PART B - The dependence of these concepts on other concepts

In the study of physics, many concepts are defined by simple equations relating them to other, more basic, concepts. Three such concepts are momentum (p), kinetic energy (E_k) and (gravitational) potential energy (E_p). The defining equations are, of course,

$$(1) \quad p = mv$$

$$(2) \quad E_k = \tfrac{1}{2}mv^2$$

$$(3) \quad E_p = mgh$$

where m = mass, v = velocity, g = gravitational field strength and h = vertical displacement.

In this way, it is seen that each of these concepts is dependent upon other, more basic, concepts. We might reasonably say that the concepts of 'mass' and 'velocity' were essential to the understanding of the concept of 'momentum', and so on.

The study of physics involves the understanding of many concepts. The following list of 50 specific concepts is not meant to be exhaustive but all of these concepts are involved in the study of physics to H-Grade level. (We have intentionally omitted such concepts as 'angular momentum' which are only relevant at C.S.Y.S. level). We would ask that you read through the list of concepts and, in the column headed 'Momentum', code each concept as 'essential', 'desirable' or 'irrelevant' as far as the understanding of the concept of momentum is concerned. Complete the columns headed 'Kinetic Energy' and 'Gravitational Potential Energy' in a similar way, but remember that each column should be completed quite independently of the other two columns.

	MOMENTUM p			KINETIC ENERGY E_k			GRAVITATIONAL POTENTIAL ENERGY E_p		
List of Concepts	ESSENTIAL	DESIRABLE	IRRELEVANT	ESSENTIAL	DESIRABLE	IRRELEVANT	ESSENTIAL	DESIRABLE	IRRELEVANT
1. Acceleration									
2. Action									
3. Addition of vectors									
4. Average acceleration									
5. Average speed									
6. Component (of a force)									
7. Conservation									
8. Direct collision									
9. Displacement									
10. Distance									
11. Efficiency									
12. Elastic collision									
13. Energy									
14. Energy input									
15. Energy output									
16. External force (of a system)									
17. Force									
18. Frequency									
19. Gravitational field strength									
20. Gravity									
21. Impulse									
22. Inelastic collision									
23. Inertia									
24. Interaction (of bodies)									
25. Interconversion (of energy)									
26. Joule									

List of concepts	MOMENTUM p			KINETIC ENERGY E_k			GRAVITATIONAL POTENTIAL ENERGY E_p		
	ESSENTIAL	DESIRABLE	IRRELEVANT	ESSENTIAL	DESIRABLE	IRRELEVANT	ESSENTIAL	DESIRABLE	IRRELEVANT
27. Kinetic energy									
28. Machine									
29. Mass									
30. Momentum									
31. Newton									
32. Newton-second									
33. Oblique collison									
34. Potential energy									
35. Power									
36. Reaction (force)									
37. Resolution of vectors									
38. Resultant									
39. Scalar									
40. Speed									
41. System									
42. Time									
43. Unbalanced force									
44. Uniform speed									
45. Uniform velocity									
46. Vector									
47. Velocity									
48. Watt									
49. Weight									
50. Work									

PART C - Concepts and propositions

In physics, concepts are often introduced in the form of propositions. A proposition is a sentence, often in the form of an equation, which links together two or more separate concepts. Thus the statement "The momentum of an object is the product of its mass and velocity" is a proposition, since it links the concept of momentum to those of mass and velocity.

The 25 propositions in the following list are all related, in some way or other, to the concepts of momentum, kinetic energy and gravitational potential energy. To ensure success at O-Grade or H-Grade Physics, it is essential in our opinion, that the pupil can recall and apply these propositions.

(1) Please indicate, for each proposition, if you would agree that it is essential for a pupil to be able to recall and apply this proposition, by putting a tick in column 1. If you are not sure, leave it blank. If you think it is not essential, put a cross (X) in column 1.

(2) Please indicate, for each proposition, the year (S3, S4 or S5) in which you would normally teach it by entering the figure 3 or 4 or 5 in column 2. If you would normally, for example, introduce the proposition in S3 and develop it in detail in S4, enter 3/4 and so on.

(3) Please indicate, for each proposition, whether or not you would normally do some practical experiment(s) and/or numerical problems to assist the pupils' understanding of the proposition, by entering the letter P (pupil experiment) or D (demonstration experiment) or N (numerical problems) in column 3. You may, of course, enter such combinations as P/N or P/D/N etc. as appropriate. If you would not normally do any experiments or numerical problems, leave it blank.

List of propositions	1 ESSENTIAL?	2 YEAR TAUGHT?	3 PRACTICAL WORK? NUMERICAL PROBLEMS?
1. Physical quantities can be classified as vectors or scalars			
2. A vector quantity is only specified if its direction as well as its magnitude is known			
3. The momentum of an object is the product of its mass and velocity			
4. Momentum is a vector quantity			
5. The product of a force and the distance moved along its line of action is a measure of the work done and of the energy transferred			
6. Energy is a scalar quantity			
7. Energy is measured in joules			
8. Power is the rate at which energy is transferred			
9. Power is measured in watts			
10. The kinetic energy of a mass m moving at a speed v is given by $E_k = \frac{1}{2}mv^2$			
11. The change in potential energy of a mass m moved a vertical distance h in a gravitational field is given by $E_p = mgh$			
12. In a system on which there are no external forces acting, kinetic energy may be converted without loss into potential energy and vice versa			
13. The impulse of a force is the product of the force and the time for which it acts			
14. Impulse is measured in newton-seconds			
15. The impulse of a force is measured by the change in momentum it produces in an object			

	1 ESSENTIAL?	2 YEAR TAUGHT?	3 PRACTICAL WORK? NUMERICAL PROBLEMS?
16. Momentum is measured in newton-seconds			
17. The rate of change of momentum of an object is a measure of the unbalanced force applied to the object			
18. Action and reaction forces are equal in magnitude but opposite in direction			
19. The efficiency of a machine is the ratio of the useful energy output to the energy input			
20. Collisions may be classified as elastic or inelastic			
21. Kinetic energy is conserved in elastic collisions			
22. In inelastic collisions, kinetic energy is converted into some other form of energy			
23. For the special case of collisions in one dimension, momentum is conserved in a system that has no external force acting on it			
24. In a system that has no external force acting on it, momentum is conserved in collisions in two dimensions.			
25. In a system on which an external force is acting, the work done by the force is a measure of the kinetic and/or potential energy transferred			

PART D - Areas of difficulty in concept learning

Previous research work has indicated that pupils have difficulties with concepts such as momentum and energy. The following 25 statements suggest possible difficulties the pupils may be experiencing.

Please indicate your opinion on each statement by putting a tick in the appropriate column.

	Strongly Agree	Agree	Disagree	Strongly Disagree
1. Pupils have difficulty in distinguishing between scalars and vectors				
2. Pupils find the idea of conservation of momentum difficult				
3. Pupils cannot distinguish between elastic collisions and inelastic collisions				
4. Pupils confuse energy with power				
5. In numerical calculations, pupils treat momentum as a scalar quantity				
6. In numerical problems involving collisions, pupils treat all collisions as one-dimensional				
7. In numerical calculations, pupils apply formulae blindly				
8. Pupils do not get sufficient practice in solving numerical problems				
9. Pupils do not have the necessary mathematical skills to solve numerical problems				
10. To many pupils, energy is just a name				
11. The concept of momentum should be introduced in S3				
12. The concept of energy should not be introduced until S3				
13. The concept of "conservation" should be introduced in S1				

	Strongly Agree	Agree	Disagree	Strongly Disagree
14. Pupils should be given more 'concrete' experience of momentum in S1 and S2				
15. Pupils should be given more 'concrete' experience of energy in S1 and S2				
16. Pupils can only develop the concepts of momentum and energy by doing practical experiments				
17. Teacher demonstrations are of little value in developing the pupils' understanding of such concepts				
18. Pupils think they understand the concepts of momentum and energy				
19. The concepts of momentum and energy are just too difficult for the average O-Grade pupil				
20. Momentum experiments with trolleys and friction-compensated runways are completely divorced from reality				
21. Pupils cannot transfer their knowledge of collisions between trolleys to 'real-life' situations				
22. Teachers expect too much of pupils				
23. Pupils have difficulty in understanding why, in any collision, momentum <u>must</u> be conserved but kinetic energy <u>may</u> be conserved.				
24. Pupils confuse momentum with inertia				

	Strongly Agree	Agree	Disagree	Strongly Disagree
25. The difficulties pupils have in understanding the concepts of momentum and energy are largely due to poor teaching				

You will possibly be aware of other difficulties your pupils have had in understanding the concepts of momentum and energy. If so, we would be pleased if you would briefly indicate these difficulties below:-

PART E - Statistical information

We would appreciate your assistance in providing some statistical data about yourself, your school and your pupils. This information will, of course, be treated as confidential but will be very useful in validating the research findings.

Please complete this section by entering ticks in the appropriate boxes.

1. What type of school are you teaching in at present?
   Comprehensive S1-S6 ☐ Comprehensive S1-S4 ☐ Other ☐

2. What is the approximate roll of the school?

S1 and S2	Under 200 ☐	200-400 ☐	Over 400 ☐
S3 and S4	Under 200 ☐	200-400 ☐	Over 400 ☐
S5 and S6	Under 100 ☐	100-200 ☐	Over 200 ☐

3. How many pupils are studying physics?

S3	Under 20 ☐	20-40 ☐	Over 40 ☐
S4	Under 20 ☐	20-40 ☐	Over 40 ☐
S5	Under 20 ☐	20-40 ☐	Over 40 ☐
S6	Under 5 ☐	5-10 ☐	Over 10 ☐

4. In physics, do your pupils make use of
   (a) a text book? ☐
   (b) duplicated notes? ☐
   (c) some combination of (a) and (b) ☐
   (d) their own notes ☐

5. If a text book is used, is it
   (a) Jardine's Physics is Fun Book 3/4 ☐
   (b) Jardine's Nat.Phil 3/4/5 or Nat. Phil 0 ☐
   (c) Burns' Higher Grade Physics ☐
   (d) Some other book (e.g. ....) ☐

PART E (continued)

6. How often, on average, would your pupils do practical experiments?

   (a) Every lesson ☐
   (b) Two out of every three lessons ☐
   (c) Once per week ☐
   (d) Once per month ☐

7. In your opinion, is your school

   (a) well equipped ☐
   (b) reasonably equipped ☐
   (c) poorly equipped ☐

   for doing practical experiments in physics?

8. When doing practical experiments, do your pupils make use of

   (a) Jardine's Nat.Phil. Workbooks 3/4/5? ☐
   (b) some other book? (e.g. ....) ☐
   (c) worksheets produced in the school? ☐

9. At the end of this current session, will you be presenting pupils for

   (a) O-Grade Physics? Yes ☐ No ☐
   (b) H-Grade Physics Yes ☐ No ☐
   (c) C.S.Y.S. Physics? Yes ☐ No ☐

10. What previous experience do you have of presenting pupils for

   (a) O-Grade Physics? 1-2 Yrs ☐ 3-5 Yrs ☐ More than 5 Yrs ☐
   (b) H-Grade Physics? 1-2 Yrs ☐ 3-5 Yrs ☐ More than 5 Yrs ☐
   (c) C.S.Y.S. Physics? 1-2 Yrs ☐ 3-5 Yrs ☐ More than 5 Yrs ☐

11. Have you any experience as a marker of S.C.E. O-Grade or H-Grade Physics?

   Yes ☐ No ☐

NEWTONIAN MECHANICS

Sub-section J_1 , J_2 . Time, velocity and acceleration

A. Cognitive

Pupils should acquire the ability to:

1. recall some methods of measuring time intervals
2. recall that the frequency of a regularly repetitive motion is equal to the greatest of the strobe frequencies required to 'stop that motion'
3. recall that an object falling freely near the Earth's surface moves with a uniform acceleration of approximately 10 m s^{-2}
4. recall an experiment to record the motion of an object falling vertically
5. classify physical quantities as vectors or scalars
6. recall that vector quantities are only specified if their direction as well as their magnitude is known
7. explain how a regularly repetitive motion can apparently be stopped by a stroboscope for a number of strobe frequencies.
8. distinguish between uniform speed and average speed
9. compute the magnitude of equal successive time intervals from strobe data
10. calculate one of the quantities speed (uniform or average), time taken and distance travelled given the other two
11. calculate one of the quantities acceleration and final speed given the other together with the initial speed and the time taken
12. draw a speed-time graph from data provided
13. use graphical methods for the vector addition of displacements and the vector addition of velocities
14. interpret qualitatively speed-time graphs in terms of speed and acceleration
15. interpret qualitatively a record (such as a tape or multi-flash photograph) of the motion of an object in terms of speed and acceleration
16. use the terms acceleration, displacement, velocity, scalar, vector, uniform speed, average speed, average acceleration correctly in context
17. compute speed from a record (such as a tape or multi-flash photograph) of the motion of an object moving with uniform speed
18. compute acceleration from a record (such as a tape or multi-flash photograph) of the motion of a uniformly accelerating object.

B. Laboratory Skills

Pupils should acquire the ability to:

1. use a simple hand stroboscope to 'stop' a regularly repetitive motion
2. use some timing devices
3. set up a vibrator and tape, and use them to record the motion of an object
4. select the appropriate timing device for a given situation.

Sub-section J_3 , J_4 . Inertia, force mass and weight

A. Cognitive

Pupils should acquire the ability to:

1. recall that while an object is acted upon by a balanced system of forces its velocity remains constant
2. recall that an unbalanced system of forces changes the velocity of the object
3. relate rest and motion in a straight line at constant speed with constant velocity
4. identify the direction in which frictional forces act on a moving object
5. recall that the acceleration of an object is in the same direction as the resultant force acting on the object
6. recall that the acceleration of an object varies directly as the resultant force on it provided the mass of the object remains constant
7. recall that the acceleration of an object varies inversely as the mass provided the resultant force remains constant
8. interpret the motion of an object falling through a fluid in terms of the forces acting on it
9. recall that if a mass of 1 kilogram is accelerating at 1 m s^{-2} the resultant force acting on it is 1 newton
10. solve simple quantitative problems involving the relationships between mass, force and acceleration
11. use vector addition to find the resultant of a number of forces
12. resolve a force into its rectangular components
13. use the approximate value 10 N kg^{-1} for the gravitational field strength near the surface of the Earth to calculate the weights of objects of different masses

14. explain how the acceleration due to gravity at a point in the Earth's gravitational field is independent of the masses of objects

15. explain how projectile motion can be treated as two independent motions, a vertical acceleration and a constant horizontal velocity

16. explain satellite motion as an extension of projectile motion

17. use the following terms correctly in context:

    unbalanced (resultant) force, component of a force, resolution, terminal velocity, mass, inertia, weight, gravity, gravitational field strength, newton, projectile, satellite

18. apply knowledge and comprehension of forces and their effects to interpret the motion of objects.

B. Laboratory Skills

Pupils should acquire the ability to:

1. select and use apparatus to cause an object to move in a straight line with either uniform or uniform acceleration.

Sub-sections J_5 , J_6 . Momentum and Energy.

A. Cognitive

Pupils should acquire the ability to:

1. recall that the momentum of an object is the product of its mass and velocity
2. recall that momentum is a vector quantity
3. recall that the product of a force and the distance moved along its line of action is a measure of the work done and of the energy transferred
4. recall that energy is a scalar quantity
5. recall that power is the rate at which energy is transferred
6. recall that, for the special case of interactions in one dimension, momentum is conserved in a system that has no external forces acting on it
7. recall that action and re-action forces are equal in magnitude but opposite in direction
8. relate action and re-action pairs of forces to the objects on which each force acts

9. calculate the kinetic energy of a moving object given its mass and speed

10. calculate the change in potential energy of a mass moved in a gravitational field

11. apply the Law of Conservation of Momentum to the solution of a simple one-dimensional interaction problems

12. solve simple problems on the interconversion of kinetic and potential energy

13. calculate the efficiency of a simple machine from consideration of the energy input and the useful energy

14. solve simple numerical problems involving energy transfer, work and power

15. interpret some simple physical phenomena in terms of momentum conservation

16. explain why a machine is not 100% efficient

17. compare elastic and inelastic collisions in terms of kinetic energy conservation

18. use the following terms correctly in context: energy, energy input, energy output, potential energy, kinetic energy, action, re-action, momentum, conservation, elastic collision, inelastic collision, efficiency, machine, work, power, joule, watt.

B. Laboratory Skills

None.

APPENDIX C

The four ability categories used in the construction of the multiple-choice papers are based on Bloom's taxonomy.

Category A. Knowledge
Recall of useful information, not inert or inoperative ideas.

Category B. Comprehension
Ability to apply a principle to a situation which it is reasonable to expect most pupils to have encountered in class and where it should be obvious to the pupil which principle should be used.

Category C. Application
Ability to apply a principle to a situation which most pupils would not have encountered in class and where the pupil must first select the appropriate principle.

Category D. Highest Abilities
This broad category will include:

(i) the ability to apply principles to problem situations, the solution to which involves two or more stages;

(ii) the design of an experiment and/or the selection of apparatus of suitable range, type and sensitivity

(iii) the critical appraisal of measurements and the interpretation of data.

The four ability groupings used in the construction of the extended answer papers are as follows:

1. Communication

   Pupils should be able to

   a) state physics information including facts, terminology, conventions, concepts, principles, theories and models
   b) describe applications of physics knowledge
   c) describe familiar experiments
   d) describe the limitations in familiar apparatus and experiments
   e) explain phenomena in terms of known principles
   f) justify or give reasons for statements of explanation
   g) discuss man's interaction with his environment
   h) criticise explanations of familiar physical phenomena
   i) criticise the selection and use of apparatus in familiar experiments
   j) interpret passages of scientific literature concerned with simple physical phenomena

2. Systematic problem solving (see footnote)

   Pupils should be able to solve problems by

   a) selecting a principle or principles in the form of a mathematical model
   b) selecting appropriate data from that given, substituting numerical values and completing a calculation.

3. Data analysis (see footnote)

   Pupils should be able to

   a) plot an appropriate graph, interpolate points on a graph and extrapolate a graph
   b) compile and extend a table of data
   c) perform mathematical calculations leading to or following from other operations.

4. Creativity

   Pupils should be able to

   a) (i) devise and describe experimental procedures which they are unlikely to have encountered in class

APPENDIX E

MOMENTUM TEST QUESTIONS

1. The product mass x velocity is a measure of :-

A force
B energy
C power
D work
E momentum

2. The masses and velocities of five moving trolleys are given below:-

(i) 4 kg moving at 6 m s^{-1}

(ii) 5 kg moving at 5 m s^{-1}

(iii) 6 kg moving at 4 m s^{-1}

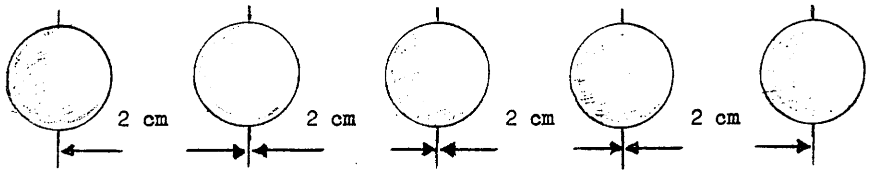
(iv) 3 kg moving at 9 m s^{-1}

(v) 8 kg moving at 3 m s^{-1}

The trolley with the greatest momentum is

A (i)
B (ii)
C (iii)
D (iv)
E (v)

3. The diagram shows a 3 kg mass moving at constant speed illuminated by a stroboscope flashing with frequency 10 Hz.



What is the momentum of the 3 kg mass?

A $\frac{10 \times 3}{2}$ kg m s^{-1}

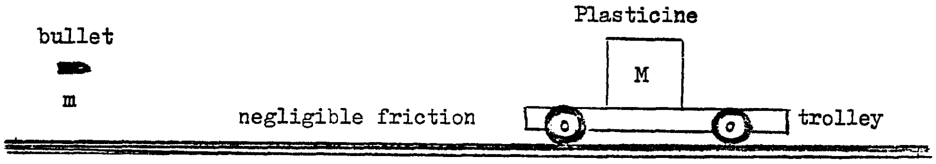
B $\frac{10 \times 2}{3 \times 100}$ kg m s^{-1}

C $\frac{10 \times 3 \times 2}{100}$ kg m s^{-1}

D $\frac{3 \times 2}{10 \times 100}$ kg m s^{-1}

E $\frac{2 \times 100}{3 \times 10}$ kg m s^{-1}

7. A bullet of mass m and momentum X is fired at a stationary trolley on which is fixed a lump of plasticine. The combined mass of trolley plus plasticine is M. The bullet strikes the plasticine and becomes embedded in it.



What is the velocity of the trolley after impact?

A $\frac{X}{m}$

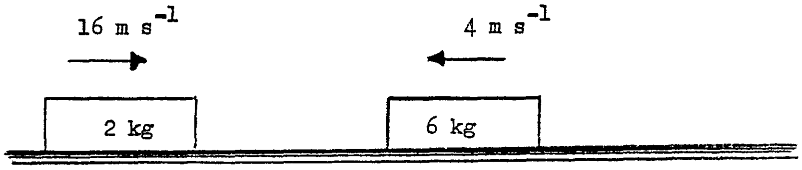
B $\frac{X}{M}$

C $\frac{X}{M + m}$

D $\frac{mX}{M + m}$

E $\frac{mX}{M}$

8. The masses and velocities of two bodies before they collide are shown in the diagram. On impact the bodies stick together.



What is the speed of the combined body after the collision?

A 1 m s^{-1}

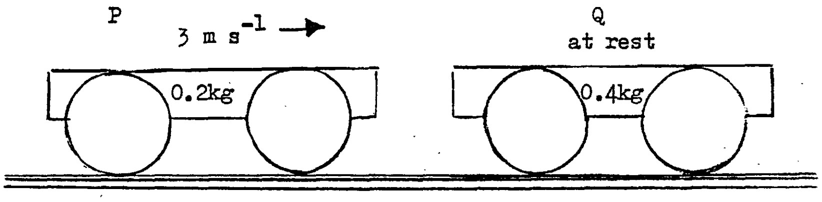
B 4 m s^{-1}

C 7 m s^{-1}

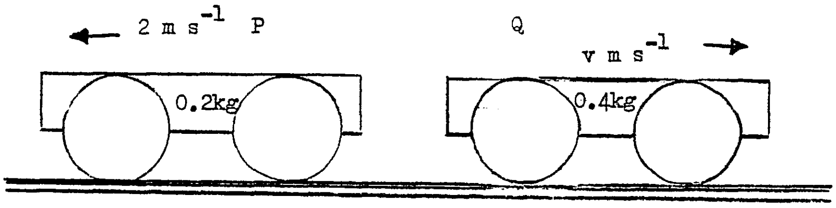
D 10 m s^{-1}

E 16 m s^{-1}

9. The diagrams show the collision between a trolley P of mass o.2 kg moving with speed 3 m s^{-1} and a stationary trolley Q of mass 0.4 kg.



Before Collision



After Collision

If the speed of trolley P after the collision is 2 m s^{-1}, what is V the speed of trolley Q?

A 1.0 m s^{-1}

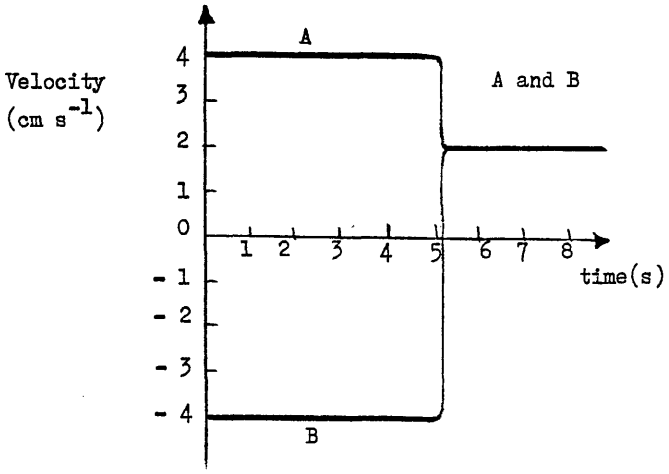
B 1.5 m s^{-1}

C 2.0 m s^{-1}

D 2.5 m s^{-1}

E 5.0 m s^{-1}

10. The velocity-time graph shows a collision between two trolleys A and B on level surface



If the mass of trolley A is 0.6 kg, what is the mass of trolley B?

A 0.15 kg
B 0.2 kg
C 0.3 kg
D 0.4 kg
E 0.6 kg

11. The kinetic energy of a 2 kg mass is 16 J. What is its momentum?

A 2 kg m s^{-1}

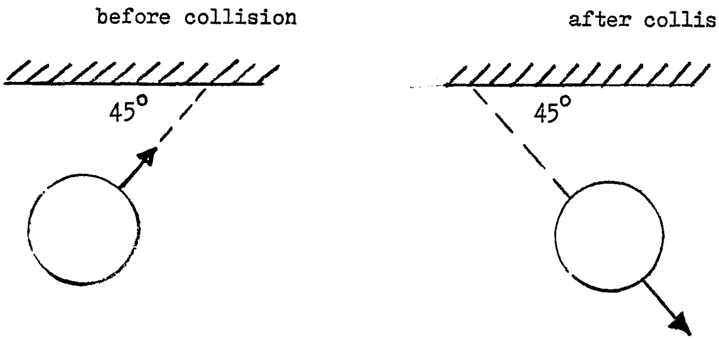
B 4 kg m s^{-1}

C 8 kg m s^{-1}

D 16 kg m s^{-1}

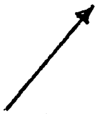
E 80 kg m s^{-1}

12. The diagrams below show the collision between a moving ball and a wall

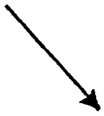


Which vector represents the impulse exerted by the ball on the wall ?


(A)

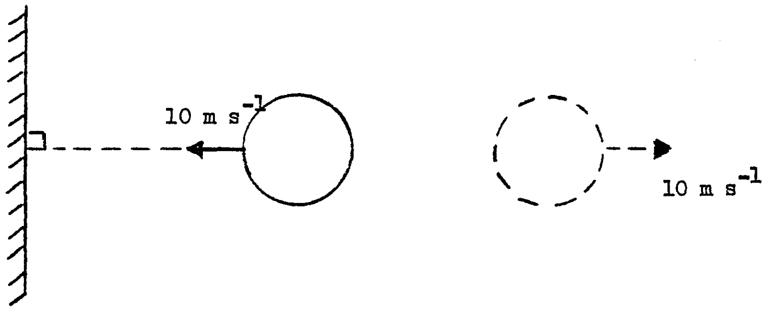

(B)


(C)


(D)


(E)

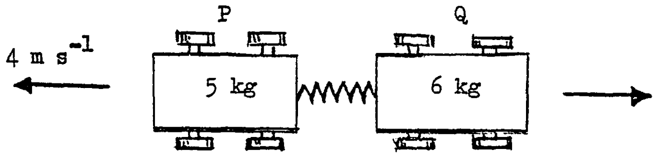
12. A rubber ball of mass 0.25 kg is thrown perpendicularly against a wall with a speed of 10 m s^{-1} and rebounds with the same speed.



The change of momentum of the ball is

A zero
B 2.5
C 5 kg m s^{-1}
D 12.5 kg m s^{-1}
E 20 kg m s^{-1} .

14. Two trolleys, P and Q stand at rest with a compressed spring between them as shown.



When the spring is released, trolley P moves off to the left at 4 m s^{-1}. The velocity of trolley Q to the right is given by

A $\frac{6 \times 5}{4}$ m s^{-1}

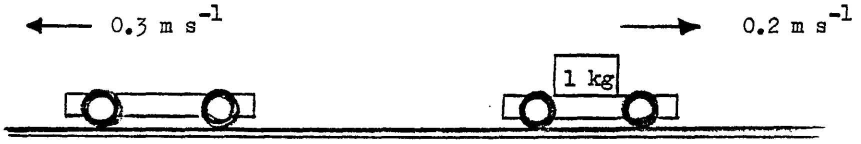
B $\frac{50 \times 40}{6}$ m s^{-1}

C $\frac{(50 + 60)}{4}$ m s^{-1}

D $\frac{(5 + 6)}{4}$ m s^{-1}

E $\frac{5 \times 4}{6}$ m s^{-1}

15. Two identical trolleys, one having a 1 kg mass fixed to it, are exploded apart on a level runway.



The speeds of the trolleys after the explosion are as shown. The mass of each trolley is:-

A $\frac{2}{3}$ kg

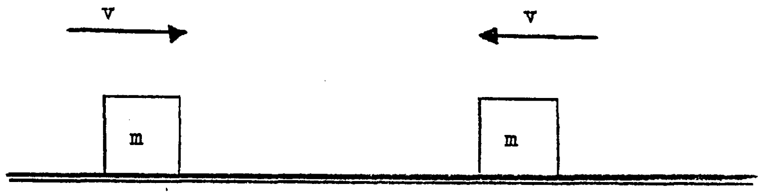
B 1 kg

C 3/2 kg

D 2 kg

E 5/2 kg.

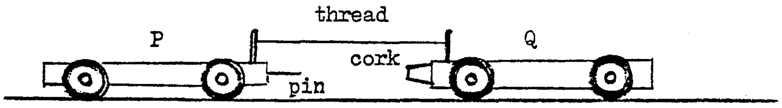
16. Two bodies each of mass m have speeds v as shown.



What is the total momentum and total kinetic energy of the two bodies?

	momentum	kinetic energy
A	2 mv	mv^2
B	mv^2	2 mv
C	0	mv^2
D	mv^2	0
E	0	0

17. Two free-running trolleys P and Q are on a level surface and are joined by a stretched elastic thread.



On impact the trolleys stick together and move slowly to the left.
This shows that trolley Q:-

A has a greater mass than P
B was moving faster than P at impact
C was released shortly before P
D had a greater acceleration than P before impact
E exerted a greater force than P at impact.

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18. A spacecraft of mass m moving with velocity v is separated into two parts by 'explosive bolts'. The larger part of mass $\frac{2}{3}$ m continues along the original course with velocity $\frac{3}{4}$ v. What is the velocity of the smaller part?

A $\frac{v}{2}$

B $\frac{3}{4}$ v

C v

D 3/2 v

E 2 v

19. An impulse applied to a body of mass m increases its speed from v_1 to v_2 without change of direction. The magnitude of the impulse is given by the expression:-

A $mv_1 + mv_2$

B $mv_2 - mv_1$

C $m/v_1 + v_2$

D $\frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2$

E $\frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$

20. A mass of 2 kg is brought to rest in 0.1 s by a constant force of 1 N. What was the velocity of the mass before the force began to act?

A 0.05 m s^{-1}

B 0.1 m s^{-1}

C 0.2 m s^{-1}

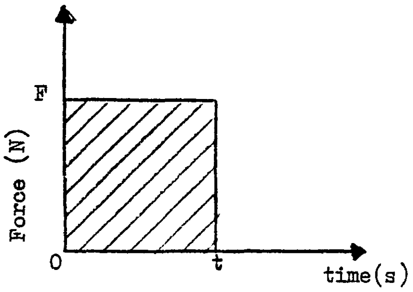
D 10 m s^{-1}

E 20 m s^{-1}

21. If the momentum of a ball of mass 0.5 kg is 5.0 kg m s^{-1}, its kinetic energy is

A 2.5 J
B 5.0 J
C 6.25 J
D 12.5 J
E 25 J

22. A body is acted on by a constant force F for a time t seconds. The force-time graph is shown



The shaded area represents the

A acceleration of the body
B distance travelled by the body
C work done on the body
D impulse of the force on the body
E change in kinetic energy of the body

23. An unbalanced force of 80 N acts on a trolley of mass 4 kg for a time of 0.2 s. The change of momentum of the trolley is

A 8 kg m s^{-1}

B 16 kg m s^{-1}

C 20 kg m s^{-1}

D 320 kg m s^{-1}

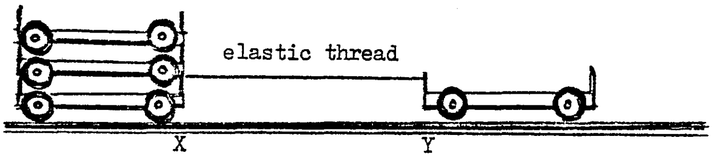
E 400 kg m s^{-1}

24. The ram of a pile driver of mass 500 kg drops on to a pile with a speed of 3 ms^{-1} .

If the ram comes to rest in 0.5 s, the force exerted on the pile is:

A 1500 N
B 3000 N
C 5000 N
D 15 000 N
E 30 000 N

25. Identical trolleys are set up as shown and connected by an elastic thread. The trolleys are pulled apart until their separation is 1 m.



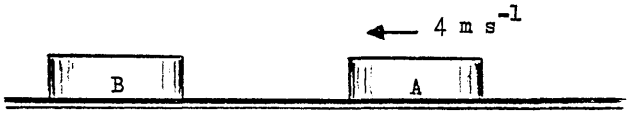
They are then released at the same time and collide at a distance of :-

A 25 cm from X
B 25 cm from Y
C 50 cm from X
D $\frac{100}{3}$ cm from X
E $\frac{100}{3}$ cm from Y

26. In an elastic collision between two bodies, what changes occur in their total kinetic energy and total momentum?

	Total kinetic energy	Total momentum
A	decreases	decreases
B	decreases	no change
C	no change	no change
D	no change	decreases
E	decreases	increases

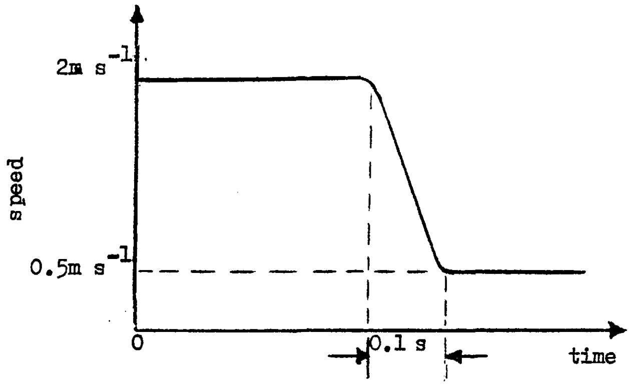
27. In the diagram below, A has a mass of 2 kg. It travels to the left at 4 m s^{-1} on a level, frictionless surface, collides with a stationary mass B and rebounds to the right with a speed of 1 m s^{-1}.



The force exerted by A on B during impact was :-

A 0.4 N
B 1.5 N
C 2.5 N
D 6.0 N
E 10.0 N

28. A trolley of mass 4 kg collides with and sticks to a stationary trolley of mass 12 kg. Here is a graph of speed against time for the 4 kg trolley.



The average force exerted on the 12 kg trolley during the collision is :-

A 20 N
B 60 N
C 80 N
D 180 N
E 240 N

29. The momentum of a trolley of mass 4 kg is changed from 6 kg m s^{-1} to 24 kg m s^{-1} by a constant force of 3 N. For how long does the force act on the trolley to cause this momentum change?

A 1.5 s
B 2 s
C 6 s
D 8 s
E 24 s

30. During a course adjustment a rocket ship of mass 50 000 kg uses 50 kg of fuel in its main motors. The fuel leaves the motors at an average speed of 1000 ms^{-1}.

The change in speed of the rocket will be approximately

A $\frac{1}{10}$ m s^{-1}

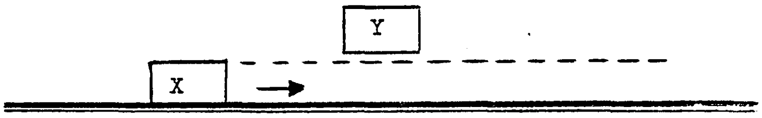
B 1 m s^{-1}

C 10 m s^{-1}

D 20 m s^{-1}

E 50 m s^{-1}

31. In the diagram below, blocks X and Y are of equal mass and the horizontal surface can be considered to be frictionless. Initially, Y is at rest just above the level of X, which is indicated by the dotted line. When X, moving at a uniform velocity, passes under Y, block Y drops on to and sticks to block X.



How does the final momentum and kinetic energy of the <u>combined</u> blocks compare with the original momentum and kinetic energy of block X?

	Momentum	Kinetic Energy
A	same	doubled
B	halved	doubled
C	same	same
D	same	halved
E	halved	same

32. Newton's second law of motion may be expressed in terms of the symbols m, v, u and t where these symbols have their usual meanings. What is the expression for the unbalanced force F?

A $\frac{\frac{1}{2}mv^2 + \frac{1}{2}mu^2}{t} = F$

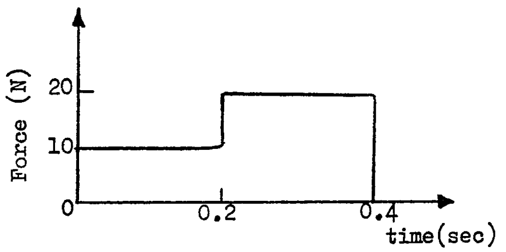
B $\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = F$

C $(mv - mu)t = F$

D $\frac{mv + mu}{t} = F$

E $\frac{mv - mu}{t} = F$

33. The graph shows how the force acting on a mass of 2 kg varies with time



If the mass has an initial velocity of 1 m s^{-1}, what is its velocity after 0.4 seconds?

A 3 m s^{-1}

B 4 m s^{-1}

C 5 m s^{-1}

D 6 m s^{-1}

E 7 m s^{-1}

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34. When a golfer hits a golf ball of mass 0.05 kg it is in contact with the club head for 0.01 s. The ball leaves the club with a velocity of 80 m s^{-1}. What average force is exerted by the club head on the ball?

A $\frac{0.05 \times 80}{0.01}$ N

B $\frac{80}{0.01 \times 0.05}$ N

C 0.05 x 80 N

D 0.05 x 80 x 0.01 N

E $\frac{80 \times 0.01}{0.05}$ N.

35. A spaceship of mass 1000 kg is travelling at 1000 m s^{-1} through deep space when its engines are fired to give a thrust of 10^5N for 10 seconds.

What is the new speed of the spaceship assuming that the fuel used has been negligible?

A 1000 m s^{-1}

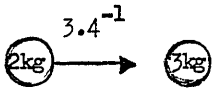
B 1100 m s^{-1}

C 1600 m s^{-1}

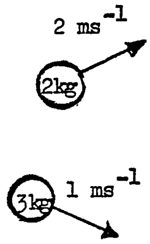
D 2000 m s^{-1}

E 10000 m s^{-1}

36. The diagrams below show a collision between a 2 kg mass moving at 3.4 m s^{-1} and a stationary 3 kg mass.

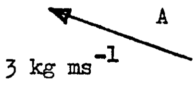


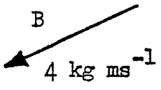
Before collision

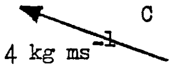


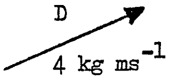
After collision

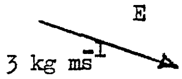
Which vector represents the change in momentum of the 2 kg mass ?



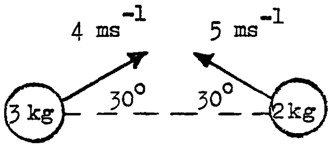




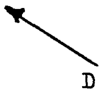


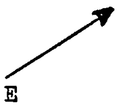


37. Two spheres of mass 3 kg and 2 kg respectively, are moving as shown. They collide and stick together.

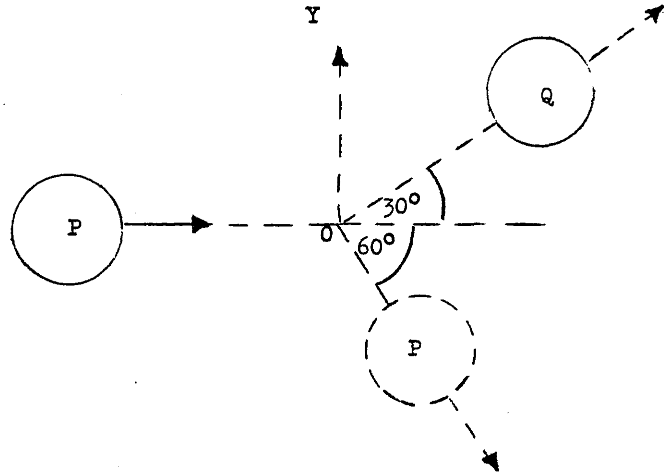


The direction in which they move off is indicated by





38. A puck P of mass 0.5 kg, travelling in the direction shown at 2 m s^{-1} collides with a stationary puck Q of the same mass at O and the two move off as shown.



After the collision the total momentum in the direction OY is

A 1.00 kg m s^{-1}

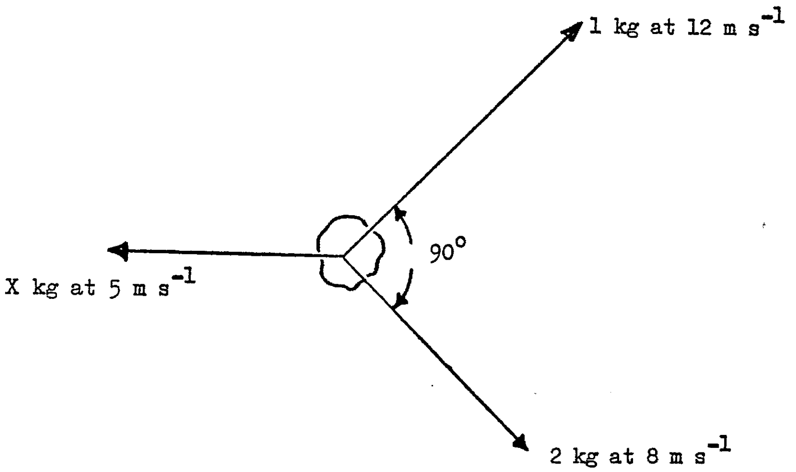
B 0.86 kg m s^{-1}

C 0.50 kg m s^{-1}

D 0.46 kg m s^{-1}

E zero

39. An explosion blows a rock into three parts as shown in the diagram.



What is the mass of fragment X?

A 3 kg
B 4 kg
C 5 kg
D 6 kg
E 7 kg

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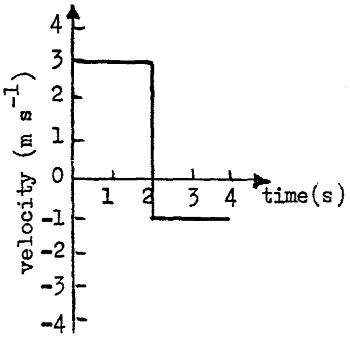
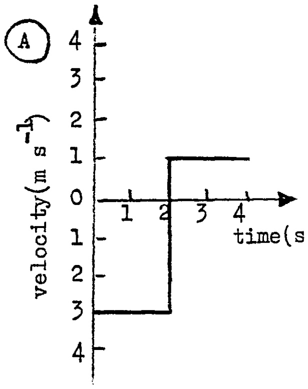
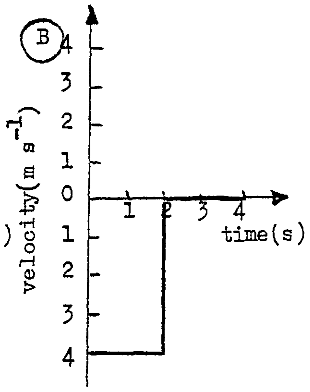
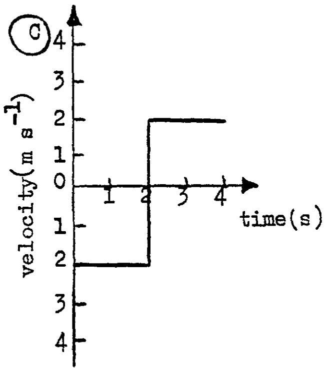
40. Two trolleys P and Q of equal mass collide without loss of kinetic energy. The velocity-time graph shows the motion of trolley P before and after the collision

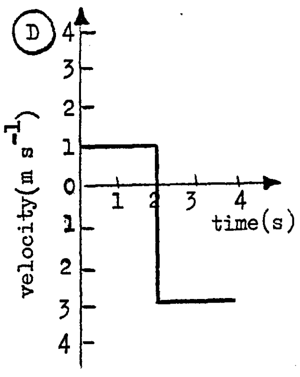


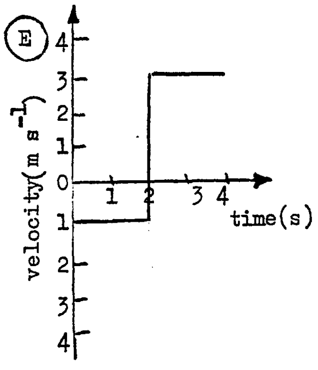
Which of the following velocity-time graphs could represent the motion of trolley Q during the same interval of time?











APPENDIX F

ENERGY TEST QUESTIONS

1. Which of the following is a SCALAR quantity?

A momentum
B potential energy
C force
D velocity
E acceleration

2. The kinetic energy of a particle of mass m travelling at speed v is given by :-

A $\frac{1}{2}mv$
B mv^2
C $\frac{1}{2}m^2v$
D m^2v^2
E $\frac{1}{2}mv^2$

3. Which expression represents energy?

A Force x distance
B Mass x velocity
C Force x time
D Mass x acceleration
E Force x velocity

4. Potential energy may be expressed in the unit:-

A kg m
B kg m s^{-1}
C W
D J
E J s^{-1}

5. A joule is the energy required to

A move a 1 kg mass 1 m against a friction force of 1 N
B give a stationary 1 kg mass a velocity of 1 m s^{-1}
C raise a 1 kg mass through a vertical distance of 1 m
D bring a 1 kg mass moving a 1 m s^{-1} to rest in 1 m
E accelerate a 1 kg mass at 1 m s^{-2} for 1 s.

6. The kinetic energy of a bullet fired with velocity v is 2 J. What is the kinetic energy of the same bullet fired with velocity 4 v?

A 4 J
B 8 J
C 16 J
D 32 J
E 64 J

7. Two masses m and 2m moving along a frictionless horizontal surface collide and come to rest. Before the collision the speed and kinetic energy of the masses were

	speed	kinetic energy
A	m had greater	m had greater
B	both had same	2m had greater
C	m had greater	both had same
D	both had same	both had same
E	2m had greater	both had same

8. Here is some information, recorded at the same instant, for a certain moving object:-

Mass = 3 kg

Velocity = 4 m s^{-1}

Distance from its starting-point = 20 m

Earth's gravitational field = 10 N kg^{-1}

Frictional force acting = 4 N

The kinetic energy of the object at this instant is

A 12 J
B 24 J
C 80 J
D 240 J
E 600 J

9. Two bodies P of mass m and Q of mass 2 m are moving in the same direction. Each has the same kinetic energy.

If the same decelerating force is applied to each how do the stopping distances S_p and S_q compare?

A $S_p = S_q$

B $S_p = 2\ S_q$

C $S_p = \frac{1}{2}\ S_q$

D $S_p = 4\ S_2$

E $S_p = \frac{1}{4}\ S_q$

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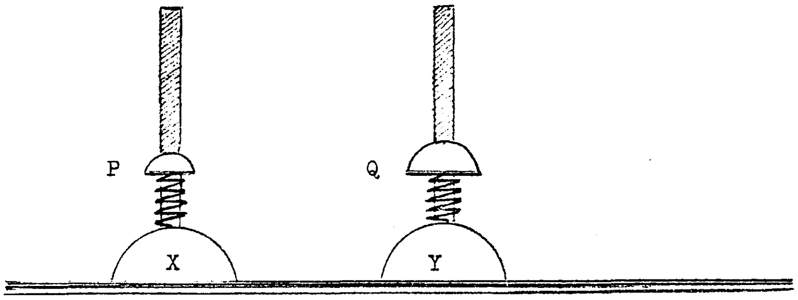
10. Hemispheres P and Q are launched vertically by identical spring launchers X and Y. Q has twice the mass of P. P reaches a maximum of 20 m and has potential energy 200 J at that height.



What is the maximum height reached by Q and the potential energy of Q at that height?

	max. ht. reached by Q	potential energy of Q
A	10 m	400 J
B	20 m	200 J
C	40 m	100 J
D	10 m	200 J
E	20 m	100 J

11. A bogie of mass 30 kg is pushed using a constant force of 50 N against a constant frictional force of 10 N.

After moving a distance of 5 m the kinetic energy of the bogie is:

A 5 x 10 J
B 5 x 40 J
C 5 x 50 J
D 5 x 30 x 10 J
E 5 x 40 x 10 J

12. A trolley of mass m is acted on by a constant unbalanced force F which changes the velocity of the trolley from u to v. The distance over which the force acts is

A $\frac{mv - mu}{F}$

B $(mv - mu) \times F$

C $\frac{mv + mu}{F}$

D $\frac{\frac{1}{2}mv^2 - \frac{1}{2}mu^2}{F}$

E $(\frac{1}{2}mv^2 - \frac{1}{2}mu^2) \times F$

13. The kinetic energy of a 2 kg mass is 16 J. What is its momentum?

A 2 kg m s^{-1}

B 4 kg m s^{-1}

C 8 kg m s^{-1}

D 16 kg m s^{-1}

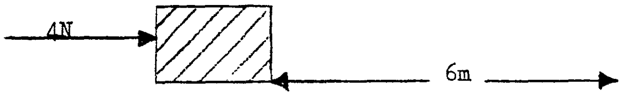
E 80 kg m s^{-1}

14. Five bodies, initially at rest, are acted upon by five different unbalanced forces through the distances shown in the following diagrams.

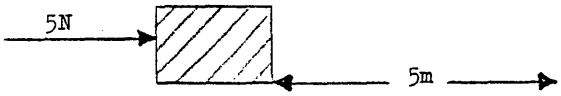
Which body gains the most kinetic energy?

A

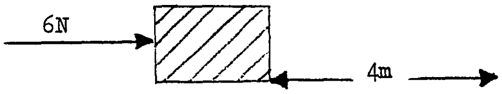
B



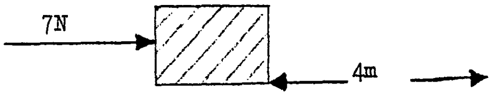
C



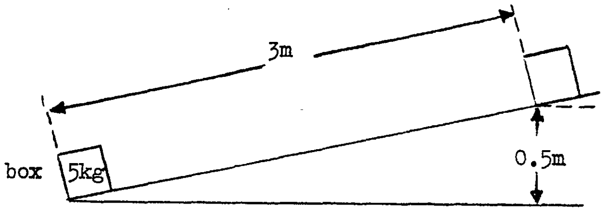
D



E



15. A box of mass 5 kg is pulled up a slope.



Neglecting friction, the potential energy gained is:

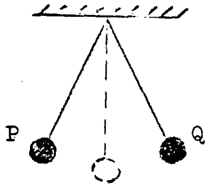
A 2.5 J
B 15 J
C 25 J
D 150 J
E 175 J

16. A stone of mass 0.2 kg is thrown upward from a point 30 m above the Earth's surface at an angle of 30^o to the horizontal. It is released with a speed of 20 m s^{-1} .

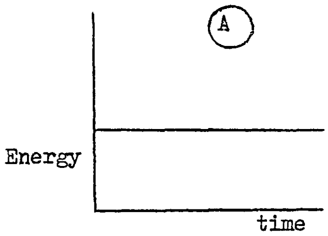
What is the total energy of the stone at the moment of release?

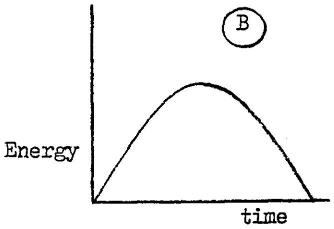
A 6 J
B 10 J
C 40 J
D 60 J
E 100 J

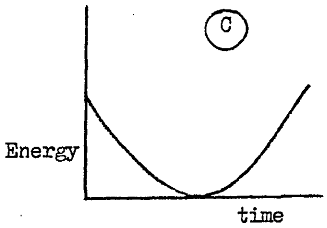
17. A simple pendulum bob swings from P to Q and back to P.

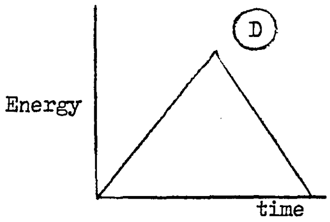


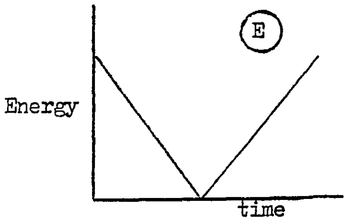
How does the total energy of the bob vary during this time?











18. Two bodies each of mass m have speeds v as shown.

What is the total momentum and total kinetic energy of the two bodies?

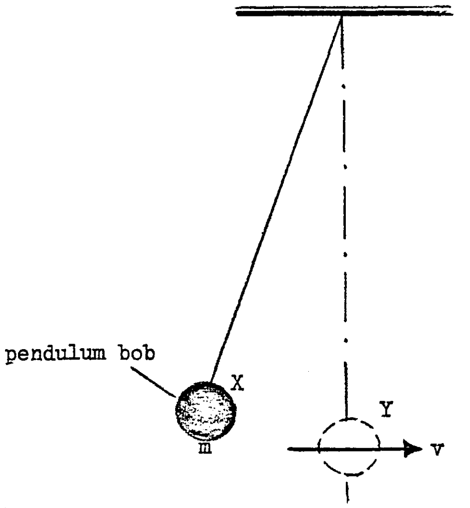
	momentum	kinetic energy
A	2 mv	mv^2
B	mv^2	2 mv
C	0	mv^2
D	mv^2	0
E	0	0

19. A man drops a ball, mass 0.1 kg from a window which is 25 m above the ground. Measurements showed that the ball was travelling at 20 m s^{-1} just before it struck the ground. How much energy is transferred as heat before the impact?

A none at all
B 1 J
C 2 J
D 5 J
E 10 J

GO ON TO NEXT PAGE

20. A pendulum bob of mass 1 kg is released at X. Its speed at Y is v.



If the mass of the bob is increased to 2 kg and it is again released at X what is its speed at Y?

A $\frac{1}{2}$ v

B $\frac{1}{\sqrt{2}}$ v

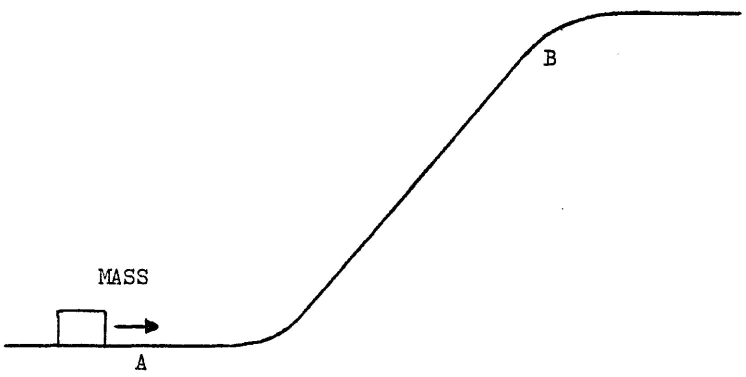
C v

D $\sqrt{2}$ v

E 2 v

GO ON TO NEXT PAGE

21. A block of mass 1 kg sliding on a frictionless rail passes point A at 8 m s^{-1} and just reaches point B. Another block of mass 2 kg passes point A and also just reaches point B.



The speed of the 2 kg mass as it passes A is

A 2 m s^{-1}

B 4 m s^{-1}

C 8 m s^{-1}

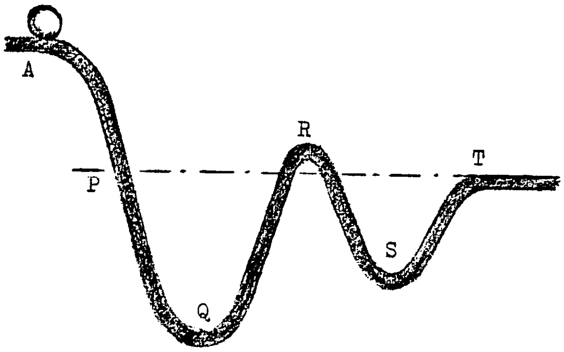
D 16 m s^{-1}

E 32 m s^{-1}

22. If the momentum of a ball of mass 0.5 kg is 5.0 kg m s^{-1}, its kinetic energy is

A 2.5 J
B 5.0 J
C 6.25 J
D 12.5 J
E 25 J

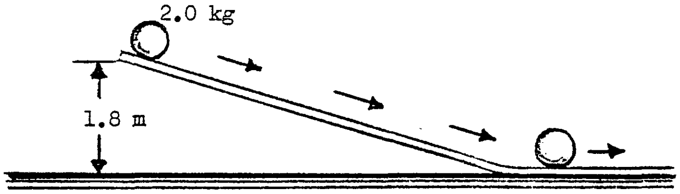
23. A ball-bearing is released from rest at A and rolls along a curtain rail bent into the shape shown below.



Where is the speed of the ball-bearing greatest?

A At P
B At Q
C At R
D At S
E At T

24. A ball of mass 2.0 kg rolls from rest down the ramp shown and 'takes off' horizontally at the foot of the ramp.



Assuming that there is negligible friction, the horizontal velocity of the ball as it 'takes off' is

A $\sqrt{3.6}$ m s^{-1}
B 3.6 m s^{-1}
C 6.0 m s^{-1}
D 36.0 m s^{-1}
E impossible to determine unless the length of the ramp is given

25. A ball of mass 0.5 kg falls from a height of 4 m on to a horizontal floor and rebounds to a height of 3 m. What is the change in kinetic energy when the ball rebounds?

A 0.5 J
B 1.5 J
C 5 J
D 15 J
E 20 J

26. In an inelastic collision, which physical quantities are conserved?

	total energy	kinetic energy	momentum
A	✓	-	✓
B	✓	✓	✓
C	✓	-	-
D	✓	✓	-
E	-	-	✓

27. In an elastic collision between two bodies, what changes occur in their total kinetic energy and total momentum?

	Total kinetic energy	Total momentum
A	decreases	decreases
B	decreases	no change
C	no change	no change
D	no change	decreases
E	decreases	increases

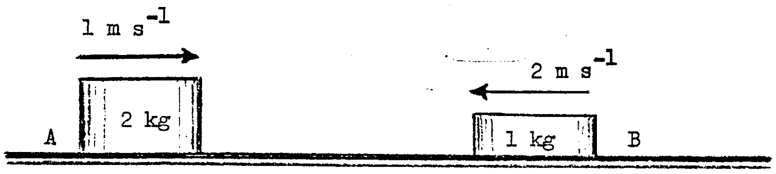
28. A 2 kg trolley moving at 2 m s^{-1} collides with a 2 kg stationary trolley. They stick together and move off with a velocity of 1 m s^{-1}.

In this collision the kinetic energy lost is

A 1 J
B 2 J
C 3 J
D 4 J
E 8 J

GO ON TO NEXT PAGE

29. The two pucks A and B are sliding without frictional losses in the same straight line with the speeds shown.



After a perfectly elastic collision the speeds of the pucks are :-

	Puck A	Puck B
A	1 m s^{-1} to the left	2 m s^{-1} to the right
B	zero	zero
C	2 m s^{-1} to the left	1 m s^{-1} to the right
D	zero	1 m s^{-1} to the right
E	1 m s^{-1} to the left	zero

30. A boat is travelling at 10 m s^{-1} against a resistive force of 100 N. The power developed by the engine is :-

A 0.1 W
B 10 W
C 100 W
D 1000 W
E 10000 W

31. A hoisting device has a power output of 240 W. It raises a load of 4 kg at a steady vertical speed of

A 1/6 m s^{-1}

B 6 m s^{-1}

C 16 m s^{-1}

D 60 m s^{-1}

E 160 m s^{-1}

32. A youth of weight 500 N carries a 15 kg box up a stair 6m high, reaching the top in 8 s.

The power which he develops is given by

A $\frac{515 \times 10 \times 6}{8}$ W

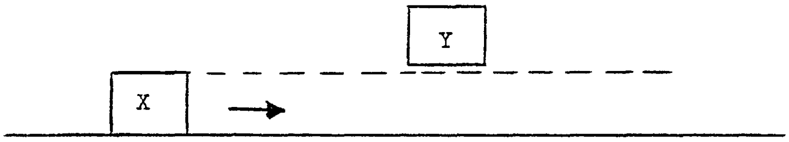
B $\frac{500 \times 6}{8}$ W

C $\frac{150 \times 6}{8}$ W

D $\frac{650 \times 6}{8}$ W

E $\frac{650 \times 10 \times 6}{8}$ W

33. In the diagram below, blocks X and Y are of equal mass and the horizontal surface can be considered to be frictionless. Initially, Y is at rest just above the level of X, which is indicated by the dotted line. When X, moving at a uniform velocity, passes under Y, block Y drops on to and sticks to block X.



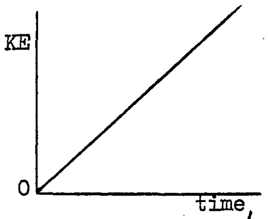
How does the final momentum and kinetic energy of the combined blocks compare with the original momentum and kinetic energy of block X?

	Momentum	Kinetic Energy
A	same	doubled
B	halved	doubled
C	same	same
D	same	halved
E	halved	same

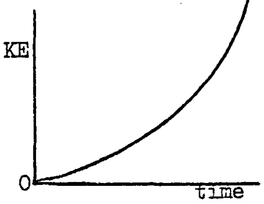
GO ON TO NEXT PAGE

34. A body starts from rest and moves with uniform acceleration. The kinetic energy-time graph for its motion is

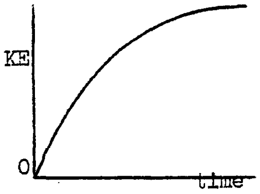
(A)



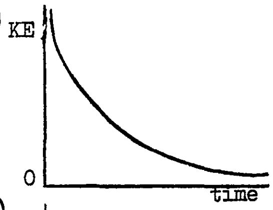
(B)



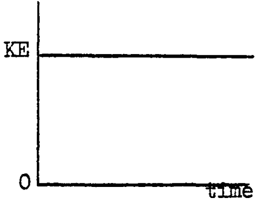
(C)



(D)

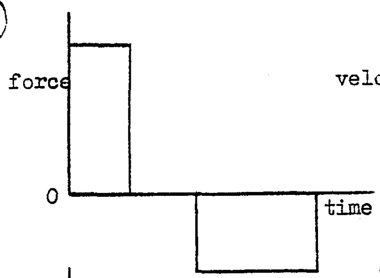


(E)

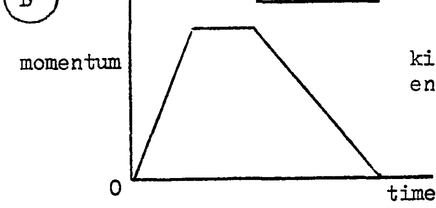


35. Four of the sketch graphs shown below apply to the motion of the same moving body. Which graph does not?

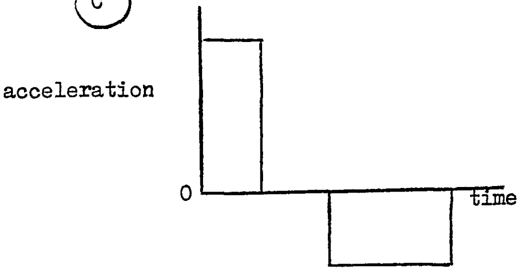
(A)



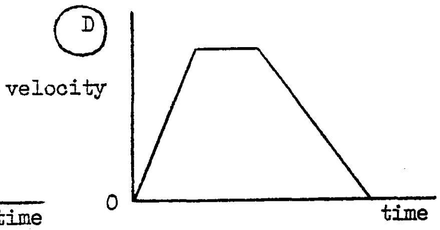
(B)



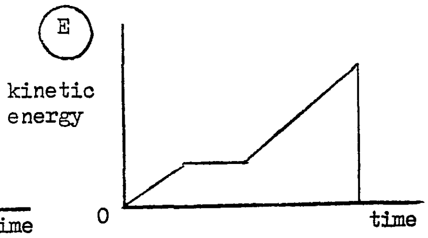
(C)



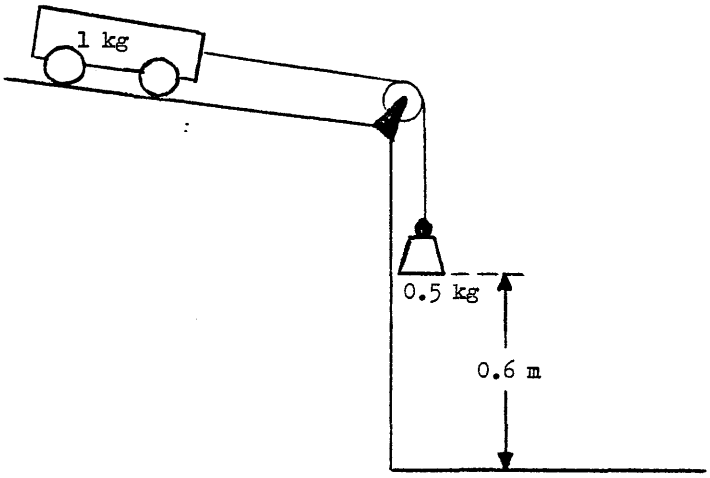
(D)



(E)



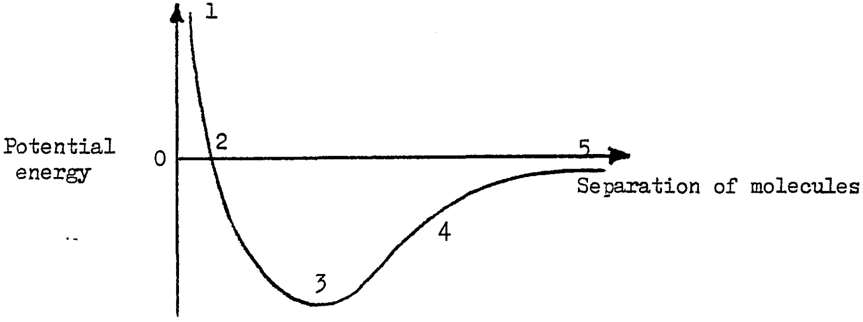
36. The sketch shows a trolley of mass 1 kg on a friction-compensated slope. The trolley is accelerated from rest by a 0.5 kg mass falling through 0.6 m.



The final kinetic energy of the trolley is

A 0.2 J
B 0.3 J
C 1 J
D 2 J
E 3 J

37. The graph shows how the potential energy between two molecules varies with their separation.



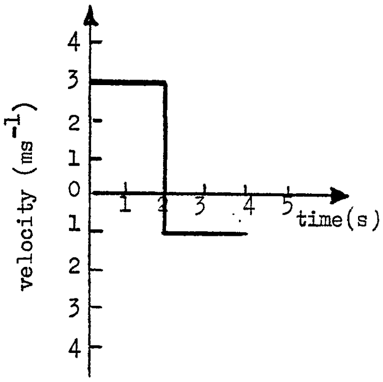
At which point on the graph are the interaction forces between the molecules zero ?

A 1
B 2
C 3
D 4
E 5

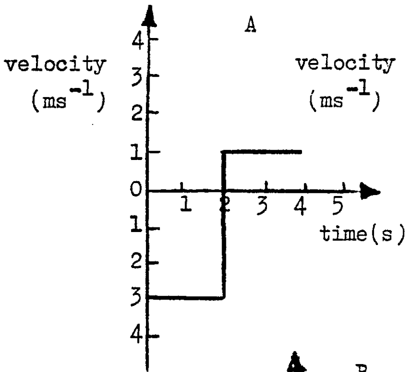
38. Two moving bodies, P and Q, have the same momentum but the kinetic energy of P is twice the kinetic energy of Q. The mass of P is

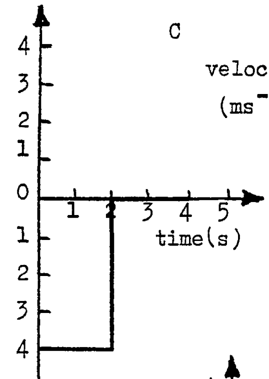
A one quarter the mass of Q
B one half the mass of Q
C the same as the mass of Q
D twice the mass of Q
E four times the mass of Q

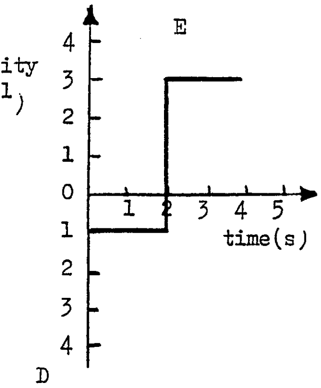
39. Two trolleys P and Q of equal mass collide without loss of kinetic energy. The velocity-time graph shows the motion of trolley P before and after the collision.

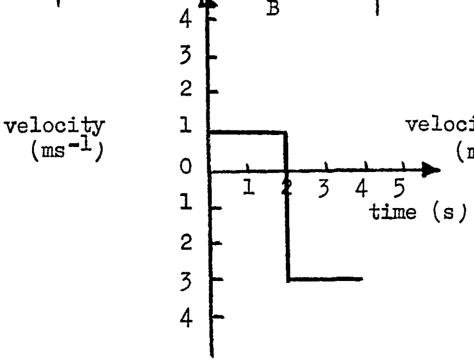


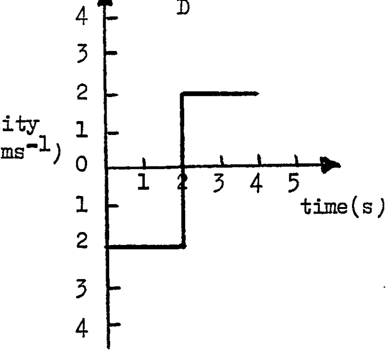
Which of the following velocity-time graphs could represent the motion of trolley Q during the same interval of time?



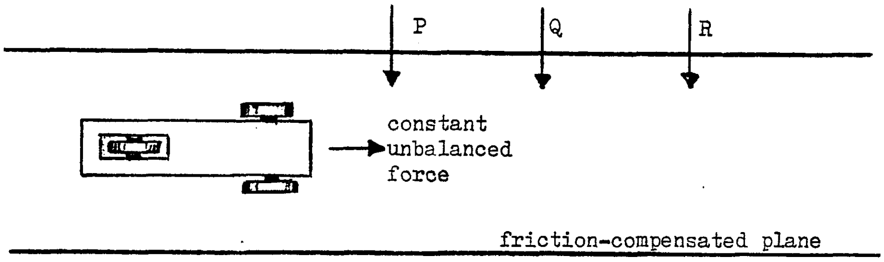








40. A trolley is pulled along a friction-compensated runway by a constant unbalanced force. The speed of the trolley is measured as it passes each of three points P, Q and R, which are equally spaced along the runway.



What might be the speed of the trolley at P, Q and R ?

	Speed at P	Speed at Q	Speed at R
A	0.1 m s^{-1}	0.1 m s^{-1}	0.1 m s^{-1}
B	0.1 m s^{-1}	0.2 m s^{-1}	0.3 m s^{-1}
C	0.1 m s^{-1}	0.3 m s^{-1}	0.9 m s^{-1}
D	0.1 m s^{-1}	0.4 m s^{-1}	0.9 m s^{-1}
E	0.1 m s^{-1}	0.5 m s^{-1}	0.7 m s^{-1}

UNIVERSITY OF GLASGOW

SCIENCE EDUCATION RESEARCH GROUP

"WHAT IS THE QUANTITY X ?"

TRIAL VERSION

A/E 2

INSTRUCTIONS FOR PART 1.

1. We are trying to find out how quickly you can identify a particular physical quantity X (eg mass, velocity, temperature, resistance, etc.) from a series of related statements, all of which apply to the quantity X. We are also interested in how confident you are about your answers.

2. On the next page you will find the first statement about the quantity X. When you have read this statement, we want you to write down the NAME of a physical quantity the statement applies to. If you think the statement can refer to more than one quantity, you should write down the names of ALL these quantities.

   After writing down your answer, put a tick in one of the five boxes to indicate how confident you are about your answer. (For the first one or two statements, you may be GUESSING what the quantity X is, but as you read more statements about the quantity X, you will sooner or later reach a stage when you KNOW what the quantity X is).

3. On each of the following pages, another statement about the quantity X is added. We want you to write down what you think quantity X could be, and to indicate how confident you are about your answer, at each successive stage, even when you feel sure you know what the quantity X is.

4. Be sure your answers are written down BEFORE you read the statements on a later page. Do NOT go back to change or add to an answer on a previous page.

5. Before you start, please complete the following:-

NAME SCOTT BARBOUR MALE ☑ /FEMALE ☐ AGE 16

SCHOOL/COLLEGE MERKSWORTH HIGH

STAGE OF STUDY: O-Grade ☐ H-Grade ☑ HND ☐ B.Sc ☐

WHAT IS THE QUANTITY X?

1. "The quantity X is proportional to the mass of a body"

Write down what you think the quantity X is. VELOCITY, MOMENTUM,

How confident are you that you have correctly identified the quantity X?
(Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	✓
I cannot be sure, but I suspect it might be....	
I think it is......, but I would like more information	
I am sure it must be........	
I know it is......and I can prove it	

NOW GO ON TO THE NEXT PAGE

WHAT IS THE QUANTITY X?

1. "The quantity X is proportional to the mass of a body".

2. "The quantity X is possessed by moving bodies".

Write down what you think the quantity X is. MOMENTUM

How confident are you that you have correctly identified the quantity X? (Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be.......	✓
I think it is.......but I would like more information	
I am sure it must be........	
I know it is.........and I can prove it	

NOW GO ON TO THE NEXT PAGE

WHAT IS THE QUANTITY X?

1. "The quantity X is proportional to the mass of a body".

2. "The quantity X is possessed by moving bodies".

3. "The quantity X is conserved in elastic collisions between bodie .

Write down what you think the quantity X is. MOMENTU

How confident are you that you have correctly identified the quantity X?
(Put a tick in the appropriate box),

I have no real idea, so I have just made a guess	☐
I cannot be sure, but I suspect it might be.......	☐
I think it is......, but I would like more information	☐
I am sure it must be.........	✓
I know it is.......and I can prove it	☐

NOW GO ON TO THE NEXT AGE

WHAT IS THE QUANTITY X?

1. "The quantity X is proportional to the mass of a body".

2. "The quantity X is possessed by moving bodies".

3. "The quantity X is conserved in elastic collisions between bodies".

4. "The quantity X can be resolved into components".

Write down what you think the quantity X is. ENERGY/MOMENTUM

How confident are you that you have correctly identified the quantity X?
(Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be......	
I think it is....., but I would like more information	✓
I am sure it must be........	
I know it is......and I can prove it	

NOW GO ON TO THE NEXT PAGE

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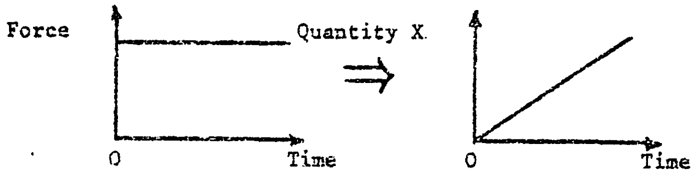
2. "The quantity X is possessed by moving bodies".

3. "The quantity X is conserved in elastic collisions between bodies".

4. "The quantity X can be resolved into components".

5. "The quantity X increases when a force is applied to a body, as indicated below:-



Write down what you think the quantity X is.

MOMENTUM

How confident are you that you have correctly identified the quantity X? (Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be......	
I think it is....., but I would like more information	
I am sure it must be...........	
I know it is......and I can prove it	✓

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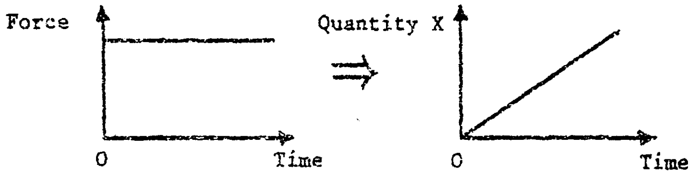

6. "The change produced in the quantity X is a measure of the impulse of the applied force."

Write down what you think the quantity X is.

MOMENTUM

How confident are you that you have correctly identified the quantity X? (Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be.......	
I think it is......., but I would like more information	
I am sure it must be.......	
I know it is......and I can prove it	✓

NOW GO ON TO THE NEXT PAGE

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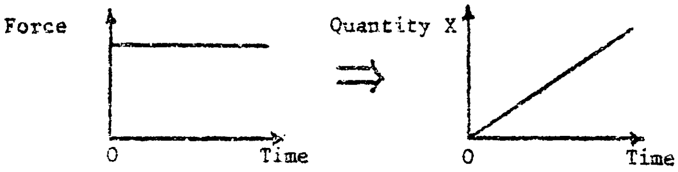

6. "The change produced in the quantity X is a measure of the impulse of the applied force."

7. "The quantity X is a vector quantity".

MOMENTUM

Write down what you think the quantity X is.

How confident are you that you have correctly identified the quantity X? (Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be......	
I think it is......, but I would like more information	
I am sure it must be.......	
I know it is......and I can prove it	✓

NOW GO ON TO THE NEXT PAGE

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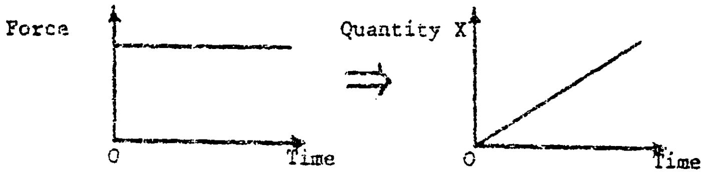
3. "The quantity X is conserved in elastic collisions between bodies".

4. "The quantity X can be resolved into components".

5. "The quantity X increases when a force is applied to a body, as indicated below:-



6. "The change produced in the quantity X is a measure of the impulse of the applied force."

7. "The quantity X is a vector quantity".

8. "The quantity X is measured in kgms^{-1}".

Write down what you think the quantity X is.

MOMENTUM

How confident are you that you have correctly identified the quantity X? (Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be......	
I think it is......, but I would like more information	
I am sure it must be.......	
I know it is........and I can prove it	✓

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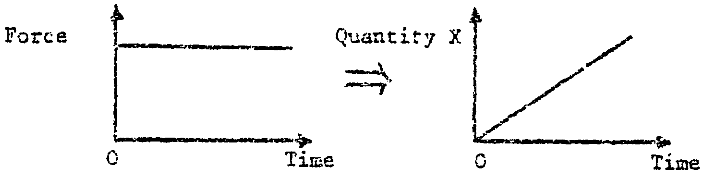
4. "The quantity X can be resolved into components".

5. "The quantity X increases when a force is applied to a body, as indicated below:-



6. "The change produced in the quantity X is a measure of the impulse of the applied force."

7. "The quantity X is a vector quantity".

8. "The quantity X is measured in kgms^{-1}."

9. "The quantity X is defined by the equation $p = mv$."

Write down what you think the quantity X is.

MOMENTUM!!

How confident are you that you have correctly identified the quantity X? (Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be......	
I think it is......, but I would like more information	
I am sure it must be......	
I know it is......and I can prove it	✓

NOW GO ON TO THE NEXT PAGE

Here is a series of statements about a DIFFERENT quantity X.

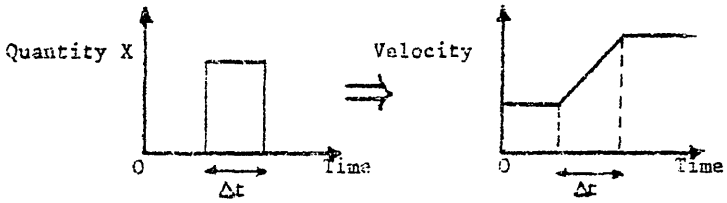
(1) The quantity X is related to the mass of a body. ☐

(2) The quantity X is involved in both elastic and inelastic collisions. ☐

(3) The quantity X can be resolved into components. ☐

(4) The quantity X can cause a body to undergo a change of velocity. ☐

(5) The change in velocity corresponding to a change in the quantity X is indicated below:- ☐



(6) The quantity X is measured by the rate of change of momentum. ☑

(7) The quantity X is a vector quantity. ☐

(8) The quantity X is measured in N. ☐

(9) The quantity X is defined by the equation F = ma. ☐

Write down what you think this quantity X is.

FORCE

Put a tick in the appropriate box to indicate the statement by which you identified this quantity X.

INSTRUCTIONS FOR PART 2.

1. We are interested here in how much you can tell us about five related quantities in mechanics - MOMENTUM, KINETIC ENERGY, GRAVITATIONAL POTENTIAL ENERGY, FORCE and IMPULSE.

2. We have provided you with a CHART to help you. Take out this chart and look at it. You will see that there are 25 numbered boxes on the chart. Each box contains ONE piece of information - a statement, a formula, a diagram - about one or more of the five quantities mentioned above.

3. Take each of the five quantities in turn, starting with MOMENTUM. Using the chart, write down, in the spaces provided overleaf, the NUMBERS of all the boxes on the chart which you think contain some information about momentum. Then do the same for each of the remaining quantities.

   Thus, if you were considering the quantity 'FORCE", you might decide that box 6 on the chart contains some information about 'force' and you would therefore write the figure '6' in one of the spaces under the heading FORCE (See overleaf)

   There are 12 spaces provided for each of the five quantities. You do NOT have to put numbers in ALL 12 SPACES. Put in only as many as you think are appropriate.

   You can enter some numbers under more than one heading.

   You need not use every number on the chart.

4. Once you have entered all the numbers for a particular quantity, look carefully on the chart at the boxes to which these numbers refer. Select the THREE numbers which, in your opinion, identify the MOST IMPORTANT features of the particular quantity being considered. Enter these three numbers, in ORDER OF IMPORTANCE, in the '1', '2' and '3' spaces at the end of the row.

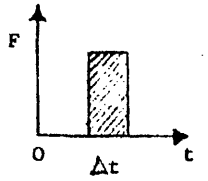
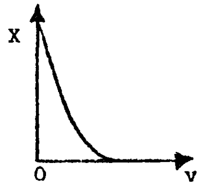
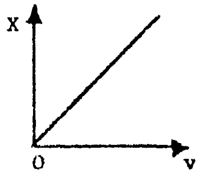
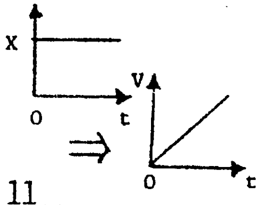
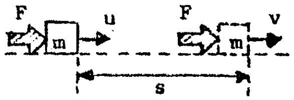
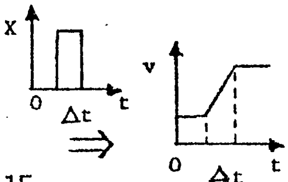
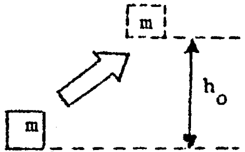
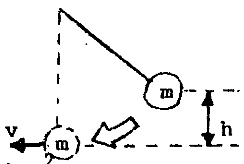
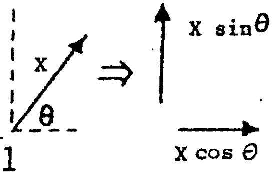
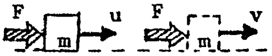
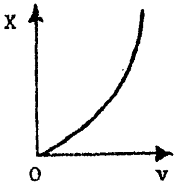
 1	$E_k = \frac{1}{2}mv^2$ 2	Measured in N 3	 4	Conserved ONLY in elastic collisions 5
$F = ma$ 6	A scalar quantity 7	 8	Measured in J 9	$E_p = mgh$ 10
 11	$F = \frac{d(mv)}{dt}$ 12	 $Fs = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ 13	Increased in an explosive collision 14	 15
$p = mv$ 16	 $\Delta E_p = mgh_o$ 17	Conserved in ALL collisions 18	 $\frac{1}{2}mv^2 = mgh$ 19	Measured in Ns 20
 21	 $Ft = mv - mu$ 22	 23	$F = m\frac{dv}{dt}$ 24	Decreased in an inelastic collision 25

CHART FOR PART 2

For each physical quantity, fill in the NUMBERS of all the boxes on the chart which refer to that quantity.

MOMENTUM

1	5	13	16	18	22						

1	2	3
16	22	1

KINETIC ENERGY

2	[illegible]	5	9	13	14	19	20				

1	2	3
2	13	19

GRAVITATIONAL POTENTIAL ENERGY

3	5	7	9	10	14	19	20				

1	2	3
10	19	20

FORCE

3	6	7	12	14	22	24	21	13			

1	2	3
6	13	19

IMPULSE

9	8	7	6	11	13	15	20	22			

1	2	3
22	13	12

Now complete the following:-

"As far as you were concerned, did the chart provided include ALL the important features of EACH of the physical quantities?"

YES ☑ NO ☐

If you answered NO, please indicate what important feature(s) were omitted from the chart:-

____

____

____

____

____

____

APPENDIX H

Here is a series of statements about a DIFFERENT quantity X.

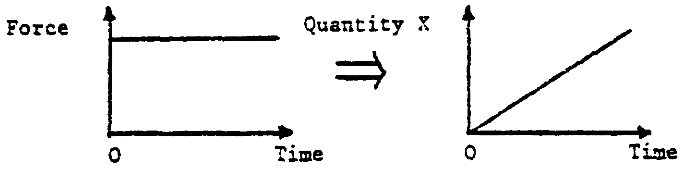
(1) The quantity X is proportional to the mass of a body. ☐

(2) The quantity X is possessed by moving bodies. ☐

(3) The quantity X is conserved in elastic collisions between bodies. ☐

(4) The quantity X can be resolved into components. ☐

(5) The quantity X increases when a force is applied to a body, as indicated below:- ☐



(6) The change produced in the quantity X is a measure of the impulse of the applied force. ☐

(7) The quantity X is a vector quantity. ☐

(8) The quantity X is measured in kgms^{-1}. ☐

(9) The quantity X is defined by the equation $p = mv$ ☐

Write down what you think this quantity X is.

Put a tick in the appropriate box to indicate the statement by which you identified this quantity X.

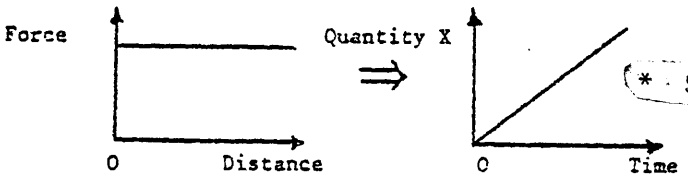
WHAT IS QUANTITY X?

1. "The quantity X is proportional to the mass of a body".

2. "The quantity X is possessed by moving bodies".

3. "The quantity X is conserved in elastic collisions between bodies".

4. "The quantity X increases when a force is applied to a body, as indicated below:-



(* · See footnote on page 183)

5. "The change produced in the quantity X is a measure of the work done by the applied force."

6. "When a body is released from a height above the ground, the quantity X increases as the body falls."

7. "The quantity X is a scalar quantity".

8. "The quantity X is measured in J".

9. "The quantity X is defined by the equation $E_k = \frac{1}{2}mv^2$."

Write down what you think the quantity X is.

How confident are you that you have correctly identified the quantity X? (Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be......	
I think it is....., but I would like more information	
I am sure it must be.........	
I know it is.......and I can prove it	

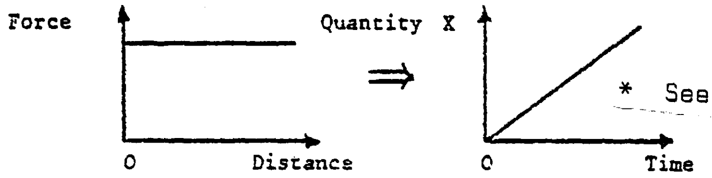
NOW GO ON TO THE NEXT PAGE

Here is a series of statements about a DIFFERENT quantity X.

(1) The quantity X is proportional to the mass of a body. ☐

(2) The quantity X is possessed by moving bodies. ☐

(3) The quantity X increases when a force is applied to a body, as indicated below:- ☐



* See footnote on page 183

(4) The change produced in the quantity X is a measure of the work done against gravity. ☐

(5) The quantity X depends on the position of the body. ☐

(6) When a body is released from a height above the ground, the quantity X decreases as the body falls. ☐

(7) The quantity X is a scalar quantity. ☐

(8) The quantity X is measured in J ☐

(9) The quantity X is defined by the equation $E_p=mgh$ ☐

Write down what you think the quantity X is.

Put a tick in the appropriate box to indicate the statement by which you identified this quantity X.

WHAT IS THE QUANTITY X?

1. "The quantity X is proportional to the mass of a body".

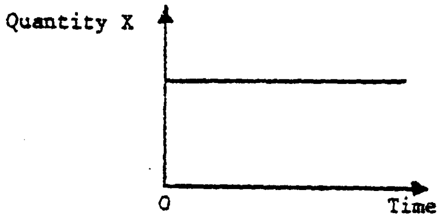
2. "The quantity X is possessed by moving bodies".

3. "The quantity X can be resolved into components".

4. "The horizontal component of the quantity X is always zero".

5. "The quantity X can cause a body to undergo a change of velocity".

6. "The graph of the quantity X against time looks like this:-



7. "The quantity X is a vector quantity".

8. "The quantity X is measured in N".

9. "The quantity X is defined by the equation $W = mg$."

Write down what you think quantity X is.

How confident are you that you have correctly identified the quantity X? (Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	☐
I cannot be sure, but I suspect it might be.......	☐
I think it is......., but I would like more information	☐
I am sure it must be........	☐
I know it is.......and I can prove it	☐

NOW GO ON TO THE NEXT PAGE

Here is a series of statements about a DIFFERENT quantity X.

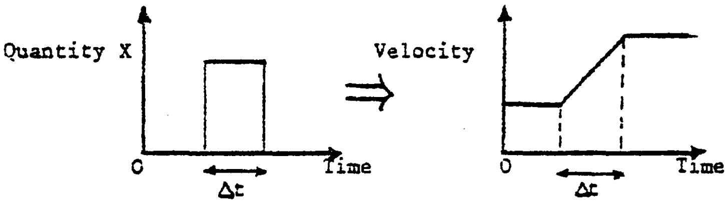
(1) The quantity X is related to the mass of a body. ☐

(2) The quantity X is involved in both elastic and inelastic collisions. ☐

(3) The quantity X can be resolved into components. ☐

(4) The quantity X can cause a body to undergo a change of velocity. ☐

(5) The change in velocity corresponding to a change in the quantity X is indicated below:- ☐



(6) The quantity X is measured by the rate of change of momentum. ☐

(7) The quantity X is a vector quantity. ☐

(8) The quantity X is measured in N. ☐

(9) The quantity X is defined by the equation F = ma. ☐

Write down what you think this quantity X is.

Put a tick in the appropriate box to indicate the statement by which you identified this quantity X.

WHAT IS THE QUANTITY X?

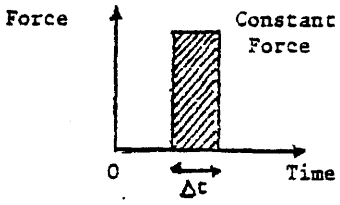
1. "The quantity X is related to the mass of a body".

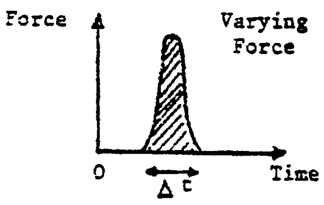
2. "The quantity X is involved in both elastic and inelastic collisions".

3. "The quantity X can be resolved into components".

4. "The quantity X can cause a body to undergo a change of velocity".

5. "If a force is applied to a body, the quantity X is indicated by the shaded area.





6. "The quantity X is measured by the change in momentum it produces".

7. "The quantity X is a vector quantity".

8. "The quantity X is measured in Ns."

9. "The quantity X is defined by the equation F.$\Delta t = \Delta mv$ "

Write down what you think quantity X is.

How confident are you that you have correctly identified the quantity X?
(Put a tick in the appropriate box).

I have no real idea, so I have just made a guess	
I cannot be sure, but I suspect it might be........	
I think it is........, but I would like more information	
I am sure it must be..........	
I know it is.......and I can prove it	

NOW GO ON TO THE NEXT PAGE

UNIVERSITY OF GLASGOW

SCIENCE EDUCATION RESEARCH GROUP

TRIAL VERSION 2

(TEACHERS)

When completed, please return to:-

Mr. Peter MacGuire,
Room 90,
Chemistry Department,
University of Glasgow.
G12 8QQ.

BACKGROUND INFORMATION

As you already know, I have been engaged in part-time educational research over the past few years. In particular I have been investigating how secondary school pupils, studying physics to O-Grade and H-Grade level, develop and use concepts such as 'momentum' or 'energy'. The most recent stage of this research has centred on trying to devise a pencil-and-paper test which would give a measure of a pupil's understanding of such concepts in two separate, but not unrelated, dimensions.

What one might call the breadth of the pupil's understanding was judged by asking them to identify a particular concept from a number of statements presented one at a time. Each statement, on its own, could be applied to more than one concept and what we were testing here was the number of valid conclusions the pupil could make at each stage and if he could relate the different statements to each other in a logical way. A valuable insight into the pupils' way of thinking was gained by asking them to estimate at each stage how confident they were about their answers.

The latter part of the test investigated the depth of the pupil's understanding of each of the concepts involved in the first part of the test. This was done by asking the pupils to select, from information provided on a chart, all the relevant information for each particular concept. This also revealed some fairly common misconceptions or part-truths (e.g. 'momentum is only conserved in elastic collisions').

A trial version of the test was administered last term to a representative sample of pupils and students (some 370 in all) and, while the detailed analysis of the results is still incomplete, certain important conclusions can already be drawn.

(a) The test was easy to administer, took some 30-40 minutes to complete, and the pupils enjoyed doing it. This was clearly encouraging.

(b) The chart used in the second part of the test could be improved in some ways. For example, much of the factual recall information, which over 90% of the test population correctly identified, could be removed. Some of the information could be reworded to make it more specific to a particular concept. More use could be made of diagrammatic, graphical and symbolic methods of conveying the information.

(c) The small group of teachers who completed the test booklet proved to be wholly unanimous in their answers. This provided a useful criterian against which the pupils' performance could be judged.

In the light of these conclusions, the trial version of the test has been revamped to make it more of a diagnostic test. It is hoped that, in this form, it could be of value to teachers in the classroom.

A revised draft of the concept chart is attached. To validate this and, I hope, to provide an 'optimum' choice of relevant "boxex" for each concept I am asking a number of experienced teachers of physics to complete the blank proforma attached.

To ensure that the final version of the test is both valid and reliable, it is necessary that as many teachers as possible take part in the validation stage. I hope you will agree to participate.

In asking you to take part in this exercise, I am conscious of the time you will be devoting to it. It should not take more than 15-20 minutes.

Any comments you may wish to make would be appreciated.

Thank you for your help.

INSTRUCTIONS

1. There are 25 numbered boxes on the Chart A. Each box contains some information about one or more of the following quantities - MOMENTUM, KINETIC, ENERGY, GRAVITATIONAL POTENTIAL ENERGY, FORCE and IMPULSE.

2. Consider each of these five quantities in turn, starting with MOMENTUM. Using the chart, write down, in the spaces provided on RESPONSE SHEET 1, the NUMBERS of ALL the boxes on the chart which you think contain some information about momentum. Then do the same for each of the remaining quantities.

3. Where the chart uses the symbol 'X', you can read this as any of the five quantities. The other symbols ('m', 'v', 'F' etc) have the usual meanings. The broad arrow (⇨) is used to link a 'before' to an 'after' situation.

4. There are 12 spaces provided for each of the five quantities. You do NOT have to put numbers in ALL 12 SPACES. Put in only as many as you think are appropriate.

   You can enter some numbers under more than one heading.

   You need not use every number on the chart.

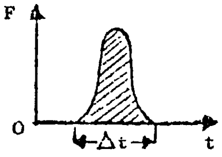
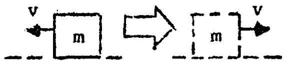
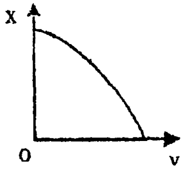
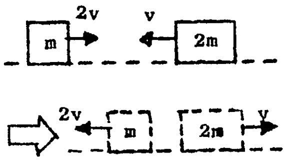
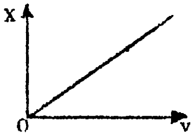
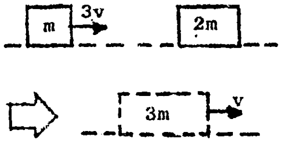
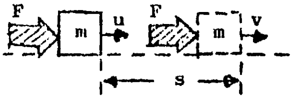
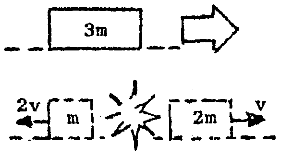
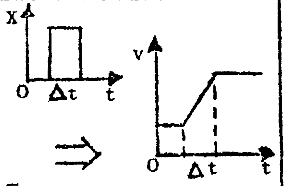
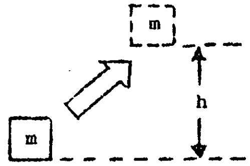
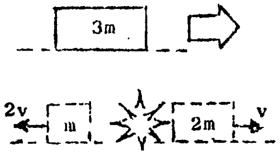
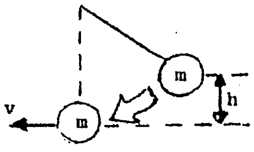
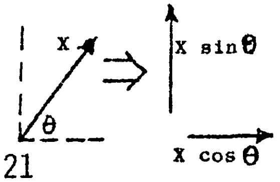
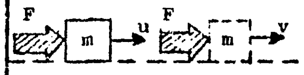
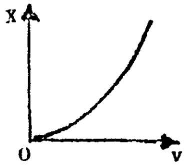
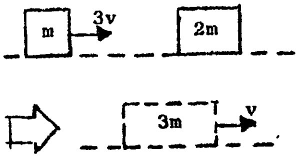
 1 X = shaded area	 Change in X = 0 2	X = 20 N 3	For a falling body  4	 5 Change in X = 0
For a falling body X = mg 6	A scalar quantity 7	For a falling body  8	X = 20 J 9	 10 Change in X = 0
A vector quantity 11	$X = \frac{d(mv)}{dt}$ 12	 $Fs = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ 13	 14 X is increased	 15
 16 Change in X ≠ 0	 17 Change in X = mgh	 18 Change in X = 0	 19 $\frac{1}{2}mv^2 = mgh$	X = 20 Ns 20
 21	 F Δt = mv − mu 22	For a falling body  23	$X = 20\ kgms^{-1}$ 24	 25 X is decreased

CHART A

RESPONSE SHEET 1

For each physical quantity, fill in the NUMBERS of ALL the boxes on the chart which you think refer to that quantity.

MOMENTUM

KINETIC ENERGY

GRAVITATIONAL POTENTIAL ENERGY

FORCE

IMPULSE

ANY OTHER COMMENTS?

RESPONSE SHEET 2

Imagine, for the moment, that you are teaching physics to H-Grade pupils.

(a) What important features about each of the following physical quantities would you emphasise in your teaching?

(b) Which of these features would you expect most pupils to find difficult?

MOMENTUM

(a)

(b)

KINETIC ENERGY

(a)

(b)

GRAVITATIONAL POTENTIAL ENERGY

(a)

(b)

FORCE

(a)

(b)

IMPULSE

(a)

(b)

APPENDIX J

UNIVERSITY OF GLASGOW

SCIENCE EDUCATION RESEARCH GROUP

WHAT IS THE QUANTITY X ?

TRIAL VERSION 2

INTRODUCTION

Can you solve this problem?

> "A chair-lift can carry 60 people at a time up a slope 300 m long. The slope makes an angle of 30° with the horizontal.
> The average mass of a person is 70 kg and the average speed of the chairs up the slope is $4\,m\,s^{-1}$. What is the minimum power output of the motor required to operate the chair-lift?
>
> (1974 H-Grade Physics, Paper 2, Q 3(a)).

To solve such a problem, it is a good idea to start by thinking about the quantities involved in the problem, and how these quantities are related to each other.

For example, in the above problem, 'power' involves 'energy' and 'time'. The 'energy' in this case is a 'gain in potential energy' which, in turn, involves 'weight' and 'vertical height'. The 'time' involves 'distance' and 'speed'.

If we now express the relationships between these quantities in a mathematical form, we can put in the numbers given in the question and work out an answer.

The essential features of successful problem-solving are

(i) deciding what quantities are involved in the problem, and
(ii) choosing the correct relationship(s) between these quantities.

In this booklet, we will concentrate on these essential features. You will NOT be asked to work out a numerical answer to a problem, but we assume you could do this if required.

All the problems in this booklet are taken from past H-Grade Physics papers. To keep things simple, we have chosen only 'mechanics' problems. These will involve such quantities as 'force','acceleration','velocity', 'momentum', 'impulse', 'kinetic energy' and 'gravitational potential energy'.

INSTRUCTIONS FOR PART A

1. We are interested here in how much you can tell us about FIVE related quantities in mechanics - MOMENTUM, KINETIC ENERGY, GRAVITATIONAL POTENTIAL ENERGY, FORCE and IMPULSE.

2. You will need CHART A for this part. Take out this chart and look at it.
   You will see that there are 25 numbered boxes on the chart.
   Each box refers to a 'quantity X'. This 'quantity X' could be one or more of the five quantities listed above. You have to identify what the 'quantity X' could be in each case.

3. Where the chart uses the symbol 'X', you can read this as one of the five given quantities. The other symbols used on the chart ('m', 'v', 'F', 'Δt' etc) have the usual meanings.

   A broad arrow (⇨) is used to link a 'before' situation to an 'after' situation.

4. Take each of the five given quantities in turn, starting with MOMENTUM. Write down, in the spaces provided overleaf, the NUMBERS of ALL the boxes on the chart in which the quantity X is, or could be, momentum.
   Then do the same for each of the remaining quantities.

5. There are 12 spaces provided for each of the five quantities.
   You do not have to put numbers in ALL 12 SPACES.

   You can put SOME numbers on the chart under more than one heading.

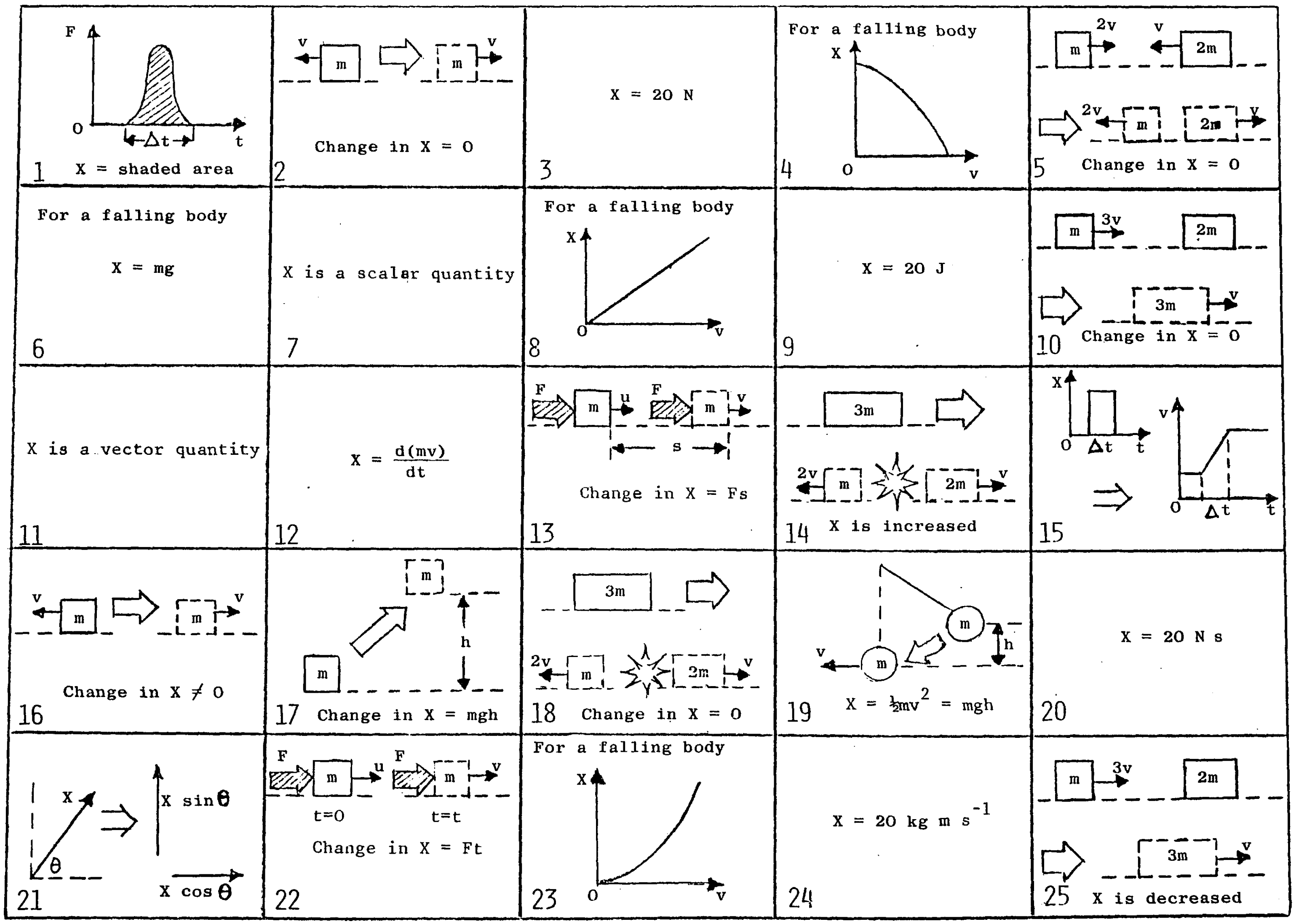

1
F
0
Δt
t
X = shaded area
2
v
m
m
v
Change in X = 0
3
X = 20 N
4
For a falling body
X
0
v
5
m
2v
v
2m
2v
m
2m
v
Change in X = 0
6
For a falling body
X = mg
7
X is a scalar quantity
8
For a falling body
X
0
v
9
X = 20 J
10
m
3v
2m
3m
v
Change in X = 0
11
X is a vector quantity
12
X = d(mv)/dt
13
F
m
u
F
m
v
s
Change in X = Fs
14
3m
2v
m
2m
v
X is increased
15
X
0
Δt
t
v
0
Δt
t
16
v
m
m
v
Change in X ≠ 0
17
m
h
m
Change in X = mgh
18
3m
2v
m
2m
v
Change in X = 0
19
m
h
v
m
X = ½mv² = mgh
20
X = 20 N s
21
X
θ
X sin θ
X cos θ
22
F
m
u
F
m
v
t=0
t=t
Change in X = Ft
23
For a falling body
X
0
v
24
X = 20 kg m s⁻¹
25
m
3v
2m
3m
v
X is decreased

CHART A

RESPONSE SHEET A

For each physical quantity, fill in the NUMBERS of ALL the boxes on CHART A in which 'X' is, or could be, that quantity,

MOMENTUM

KINETIC ENERGY

GRAVITATIONAL POTENTIAL ENERGY

FORCE

IMPULSE

INSTRUCTIONS FOR PART B

1. In this part, we are trying to find out how quickly you can positively identify a particular 'quantity X' from a series of statements, all of which can apply to the 'quantity X'.

   We are also interested in how confident you are about your answer at each step.

2. On the next page, you will find the first statement about the 'quantity X'. When you have read the statement, we want you to write down the NAME of a physical quantity to which the statement could apply. In other words, if you put the name of your chosen quantity in place of 'quantity X', the statement would be true.

   If you can think of more than one physical quantity which could replace 'quantity X' in the statement, then write down the names of ALL the possible quantities.

3. After writing down your answer, put a tick in one of the five boxes to indicate how confident you are about your answer.

4. Depending on which box you tick, you will find instructions at the bottom of the page to tell you which page to turn to.

   FOLLOW THESE INSTRUCTIONS CAREFULLY.

WHAT IS THE QUANTITY X ?

Here is the FIRST statement about the quantity X.

1. "The quantity X is proportional to the mass of a body".

Write down what you think the quantity X is

How confident are you that you have correctly identified the quantity X?
(Put a tick in the appropriate box)

I have no idea, so I have just made a guess	1	☐
I cannot be sure, but I suspect it may be..........	2	☐
I think it is......but I would like more information	3	☐
I am sure it must be.....	4	☐
I know it is........and I can prove it	5	☐

If you ticked box 1, TURN TO PAGE 6

If you ticked box 2 or 3, TURN TO PAGE 8

If you ticked box 4 or 5, TURN TO PAGE 7

IF YOU HAVE ARRIVED HERE BY NOT FOLLOWING THE INSTRUCTIONS ON THE PREVIOUS PAGE, THEN GO BACK NOW AND READ THESE INSTRUCTIONS!!

You have ticked box 1 on page 5. What did you mean by this?

1. Did you mean you had REALLY NO IDEA what the quantity X could be?

   If this is the case, then you are not thinking very hard.

   For example 'momentum' is proportional to the mass of a body. So is 'kinetic energy' or 'weight' or 'gravitational potential energy' or 'density or ....

2. Did you mean you had to GUESS because there were so many possible answers?

   If this is the case, then we would agree with you.

   Nevertheless, it might have been more appropriate to tick another box, because you have several ideas what the quantity X could be. You really need more information.

We will assume, in either case, that you can now move on to the next statement about the quantity X.

TURN TO PAGE 8

By ticking box 4 or 5 on page 5, you have indicated that you are SURE you have POSITIVELY IDENTIFIED the quantity X.

Have you considered ALL the possibilities?

For example ' momentum' is a possible answer.

But so is 'weight', 'kinetic energy','gravitational potential energy', or 'density'.

Depending on your knowledge of physics, you might also have put down 'moment of inertia' or 'angular momentum' or 'centripetal force' or 'rotational kinetic energy'.

The 'heat energy' absorbed or evolved for the same change in temperature of different masses of the same material is proportional to the mass. So also is the 'heat energy' absorbed or evolved during a change of state.

Quantities such as 'force' and 'impulse' are dependent on the mass but are not proportional to the mass. It would be more correct to say 'the effect of a force depends on the mass of the body'. Thus the 'acceleration' is inversely proportional to the mass, if the 'force' is constant.

If you now realise that you have not considered ALL the possibilities, you will appreciate that you have not yet identified the quantity X.

Even if you have considered all these possibilities can you be SURE you have identified the quantity X? Do you not need more information?

TURN TO PAGE 8

WHAT IS THE QUANTITY X ?

Here is the SECOND statement about the quantity X.

2. "Taking the dimensions of mass, length and time to be M, L and T respectively, the dimensions of the quantity X are ML^2T^{-2}".

Write down what you think the quantity X is.

How confident are you that you have correctly identified the quantity X? (Put a tick in the appropriate box).

I cannot be sure, but I suspect it might be.....	1	
I think it is......but I would like more information	2	
I am sure it must be...........	3	
I know it is......and I can prove it	4	

If you have ticked box 1 or 2, TURN TO PAGE 9

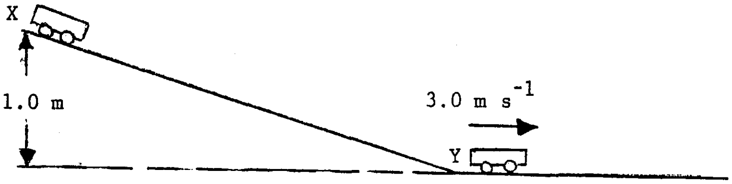
If you have ticked box 3 or 4, TURN TO PAGE 10

WHAT IS THE QUANTITY X ?

Here is the THIRD statement about the quantity X.

3. "The quantity X is involved in answering the following question".

A trolley of mass 1.0 kg is released from rest as shown from the top of a slope. When it reaches the bottom of the slope it is travelling at 3.0 m s^{-1}.



The work done against friction while moving from X to Y must have been

A 1.0 J
B 4.5 J
C 5.5 J
D 9.0 J
E 10.0 J

(1975 H-Grade Physics, Paper 1, Q 13)

Write down what you think the quantity X is.

How confident are you that you have correctly identified quantity X ?
(Put a tick in the appropriate box)

I cannot be sure, but I suspect it might be.....	1	
I think it is.....but I would like more information	2	
I am sure it must be.....	3	
I know it is.....and I can prove it	4	

If you have ticked box 1 or 2, TURN TO PAGE 10
If you have ticked box 3 or 4, TURN TO PAGE 12

WHAT IS THE QUANTITY X ?

At this stage you will have a fairly good idea what the quantity X could be.

You can have ONE more piece of information about the quantity X and you can decide what this will be.

Here are five possible questions about the quantity X.
The answer to each question is YES or NO.

(1) Can the quantity X be resolved into components? YES/NO ☐

(2) Is the quantity X conserved in elastic collisions? YES/NO ☐

(3) Is the quantity X conserved in inelastic collisions? YES/NO ☐

(4) Is the quantity X measured in J? YES/NO ☐

(5) Is the quantity X possessed by falling bodies? YES/NO ☐

You can ask only ONE question about quantity X.

EITHER Indicate, by putting a tick in the appropriate box, which of the above questions you would ask

OR Write a question of your own in the space provided below. (Remember the answer can only be YES or NO)

YOUR QUESTION

.... YES/NO
....

NOW TURN TO PAGE 11

Here are the answers to the five questions about the quantity X.

Q1 NO Q2 YES Q3 NO Q4 YES Q5 YES

If you asked some other question about the quantity X, you should be able to work out the answer to your question from the answers given above.

You should now KNOW what the quantity X is.

COMPLETE THE FOLLOWING SUMMARY

1. The quantity X is

2. The mathematical expression which DEFINES the quantity X is

3. The UNITS of the quantity X are

4. TWO other important facts about the quantity X are

NOW TURN TO PAGE 13

INSTRUCTIONS FOR PART C

1. Up till now, we have considered only ONE quantity at a time. Many problems however, involve more than one quantity. In this part of the booklet, we want you to consider ALL the quantities which could be involved in each problem.

2. On the next three pages, you will find FOUR typical H-Grade Physics questions. You should also have a CHART C. Take out this chart and look at it. You will note that it has 12 numbered boxes. Each box contains a general statement of a RELATIONSHIP between QUANTITIES. (e.g. 'impulse = change in momentum').

3. Read the first problem on page 14.
Three steps are involved in solving this problem.

(1) Impulse = average force x time
(11) Impulse = change in momentum
(111) $\text{Change in speed} = \dfrac{\text{change in momentum}}{\text{mass}}$

The NUMBERS of the boxes on chart C which CORRESPOND MOST CLOSELY to these three steps are 10, 4 and 2. These NUMBERS are entered, IN ORDER, into the spaces provided at the end of problem 1.

4. Problem 1 could also be solved using 'acceleration'

(1) $\text{Average acceleration} = \dfrac{\text{average force}}{\text{mass}}$
(11) Change in speed = acceleration x time

Using chart C, the NUMBERS of the corresponding boxes would be, IN ORDER, 6 and 7.

These numbers are entered, IN ORDER, in the SECOND set of spaces provided at the end of problem 1.

5. Problem 1 has been done for you AS AN EXAMPLE.
You now do problems 2, 3 and 4.
In each case, write the NUMBERS of the boxes on chart C which contain the relationships you would use, IN THE ORDER YOU WOULD USE THEM.

INSTRUCTIONS FOR PART C

1. Up till now, we have considered only ONE quantity at a time. Many problems however, involve more than one quantity. In this part of the booklet, we want you to consider ALL the quantities which could be involved in each problem.

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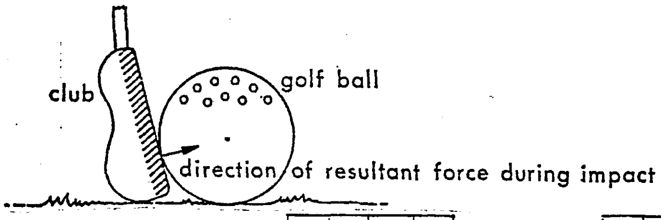
   In each case, write the NUMBERS of the boxes on chart C which contain the relationships you would use, IN THE ORDER YOU WOULD USE THEM.

PROBLEM 1 (1976 H-Grade Physics, Paper 2, Q2(a))

"A golfer hits a golf ball of mass 5.0×10^{-2}kg into the air. The club is in contact with the ball for 5.0×10^{-4}s.

Calculate the resulting speed of the ball if the average force during contact is 3.0×10^{2}N"



SOLUTION TO PROBLEM 1

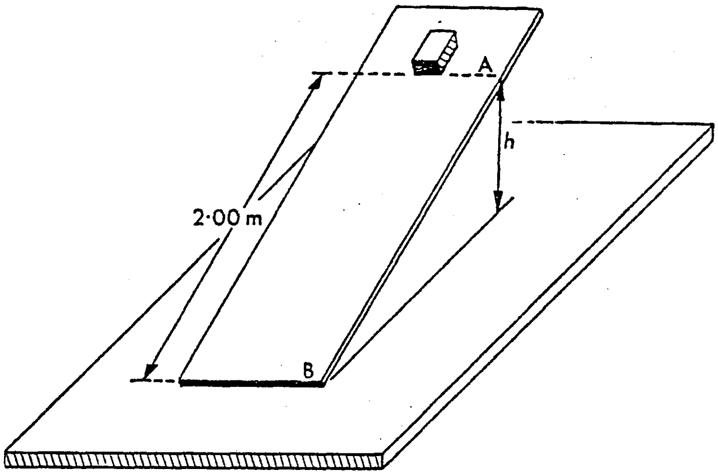
10	4	2	

or

6	7		

PROBLEM 2 (1978 H-Grade Physics, Paper 2, Q3(b))

"In an experiment, a block of mass 1.00 kg is released from rest from a point A 2.00 m up a slope as shown in the diagram. The block slides down to the point B at the bottom of the slope where its speed is measured.
When h=1.00 m, the speed of the block at B = 3.85 ms^{-1}.

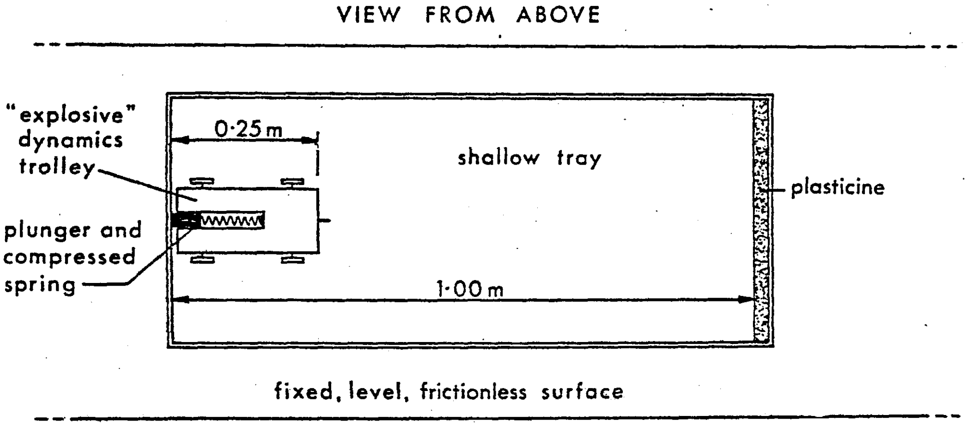


Calculate the average frictional force on the block during the experiment.

SOLUTION TO PROBLEM 2

PROBLEM 3 (1980 H-Grade Physics, Paper 2, Q2)

An "explosive" dynamics trolley of mass 1 kg is placed in a shallow tray of mass 10 kg which rests on a fixed, level, frictionless surface.



When the compressed spring is released, the plunger hits the wall of the shallow tray causing the trolley to move to the right at a speed of 0.50 m s^{-1} relative to the fixed surface. The tray moves to the left. When the trolley strikes the opposite wall of the tray, which is covered with plasticine, the whole system comes to rest again.

(a) Calculate the velocity with which the tray moves to the left.

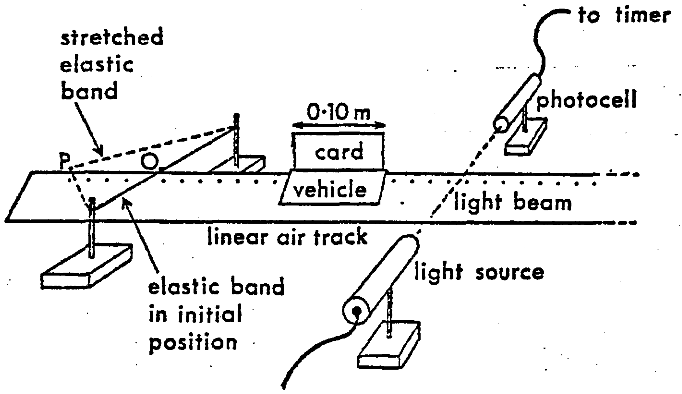
(b) Calculate the distance which the tray moves before coming to rest.

(c) The time for which the plunger is in contact with the wall of the tray is 0.02 s. Calculate the average force exerted by the plunger on the wall of the tray.

SOLUTION TO PROBLEM 3 (a) ☐☐☐☐ (b) ☐☐☐☐ (c) ☐☐☐☐

PROBLEM 4 (1977 H-Grade Physics, Paper 2, Q3(a))

A vehicle is travelling along a horizontal linear air track. A card on the vehicle passes through a light beam before the vehicle is stopped by a stretched elastic band. While the vehicle is being stopped, the centre of the elastic moves from O to P.



Results obtained from one run of the vehicle are:

Mass of vehicle and card = 1.1 kg
Length of card = 0.10 m
Time through light beam = 0.25 s
Stopping distance OP = 0.050 m

Calculate

(i) the average force exerted by the elastic band on the vehicle while it is being stopped;

(ii) the time taken by the elastic band to stop the vehicle.

SOLUTION TO PROBLEM 4 (i) (ii)

work = force x distance 1	momentum = mass x velocity 2	component of weight down slope = mg sin θ 3	impulse = change in momentum 4
average speed = $\frac{\text{distance}}{\text{time}}$ 5	force = mass x acceleration 6	acceleration = $\frac{\text{change in speed}}{\text{time}}$ 7	loss in kinetic energy = work done against resistance 8
gravitational potential energy = mgh 9	impulse = force x time 10	kinetic energy = $\frac{1}{2}mv^2$ 11	in any interaction total change in momentum = 0 12

CHART C

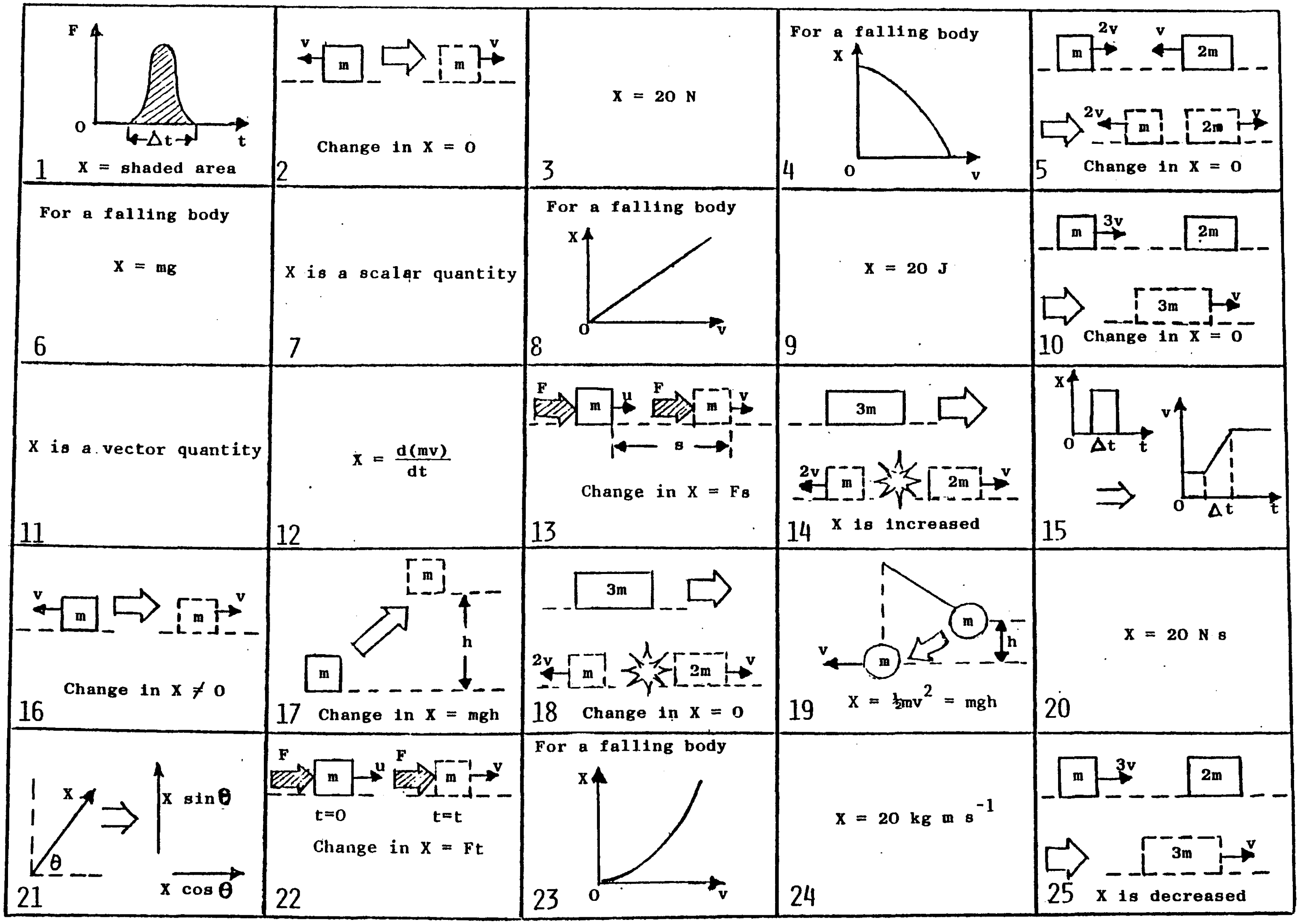

F
0
Δt
t
1
X = shaded area
v
m
v
m
2
Change in X = 0
X = 20 N
3
For a falling body
X
0
v
4
2v
v
m
2m
2v
m
2m
v
5
Change in X = 0
For a falling body
X = mg
6
X is a scalar quantity
7
For a falling body
X
0
v
8
X = 20 J
9
m
3v
2m
3m
v
10
Change in X = 0
X is a vector quantity
11
X = d(mv)/dt
12
F
m
u
F
m
v
s
Change in X = Fs
13
3m
2v
m
2m
v
14
X is increased
X
0
Δt
t
v
0
Δt
t
15
v
m
m
v
Change in X ≠ 0
16
m
m
h
17
Change in X = mgh
3m
2v
m
2m
v
18
Change in X = 0
m
h
v
m
19
X = ½mv² = mgh
X = 20 N s
20
X
θ
X sinθ
X cosθ
21
F
m
u
F
m
v
t=0
t=t
Change in X = Ft
22
For a falling body
X
0
v
23
X = 20 kg m s⁻¹
24
m
3v
2m
3m
v
25
X is decreased

CHART A

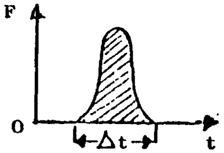
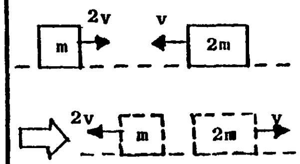
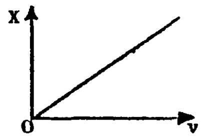
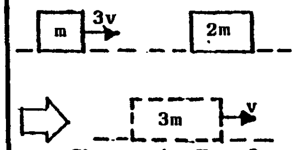
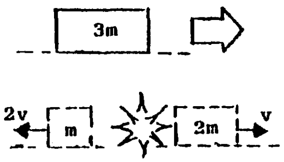
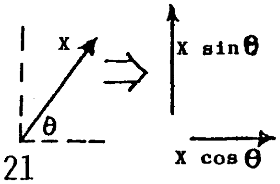
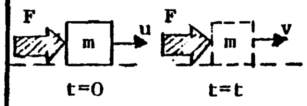
 1 X = shaded area	2	3	4	 5 Change in X = 0
6	7	For a falling body  8	9	 10 Change in X = 0
X is a vector quantity 11	12	13	14	15
 16 Change in X ≠ 0	17	 18 Change in X = 0	19	20
 21	 Change in X = Ft 22	23	X = 20 kg m s^{-1} 24	25

CHART A

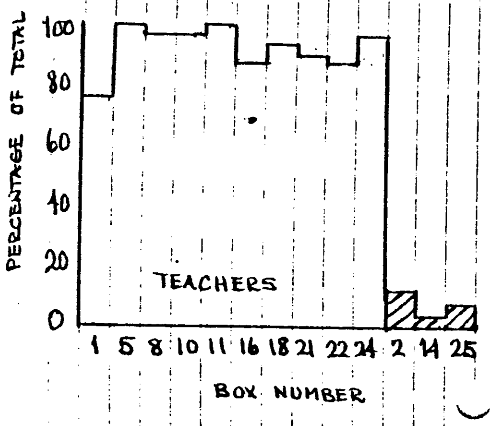
MOMENTUM SUMMARY – CHART A

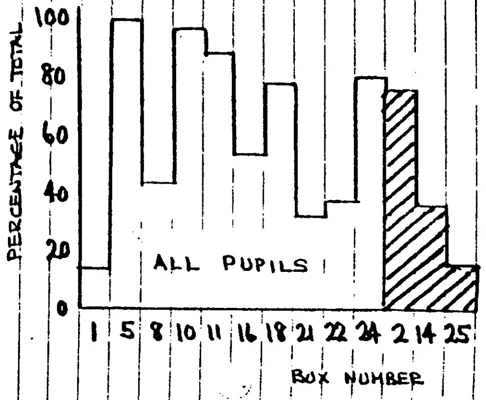
ACTUAL → ⟋ ← PERCENTAGE

TEACHERS	28	21/75	28/100	27/96	27/96	28/100	24/86	26/93	25/89	24/86	27/96	257	9.2	3/11	1/3	2/7
BOX NUMBERS		1	5	8	10	11	16	18	21	22	24	TOTAL	AVER	2	14	25
SCHOOL A	39	5/12	39/100	7/17	36/92	30/76	14/35	28/71	2/5	13/33	33/84	209	5.3	35/90	13/33	10/25
SCHOOL B	13	0/0	13/100	7/53	13/100	9/69	5/38	10/76	3/23	2/15	7/53	69	4.3	9/69	3/23	1/8
SCHOOL C	17	3/17	15/88	3/17	16/94	14/82	3/17	13/76	9/52	5/29	9/52	90	5.3	14/82	6/35	1/6
SCHOOL D	24	2/8	23/95	8/33	22/91	18/75	14/58	19/79	10/41	12/50	16/66	144	6.0	18/75	7/29	3/12
SCHOOL E	15	0/0	15/100	9/60	15/100	14/93	9/60	13/86	0/0	0/0	14/93	83	5.5	14/93	7/47	0/0
SCHOOL F	35	6/17	35/100	11/31	35/100	32/91	11/31	29/82	13/37	12/34	35/100	219	6.3	29/82	8/23	6/17
SCHOOL G	14	2/14	13/92	5/35	11/78	13/92	6/42	10/71	5/35	2/14	9/64	76	54	12/85	7/50	3/21
SCHOOL H	13	2/15	11/84	3/23	12/92	12/92	10/76	11/84	1/7	5/38	13/100	80	6.2	4/30	3/23	3/23
SCHOOL I	25	3/12	23/92	6/24	22/88	17/68	13/52	21/84	11/44	4/16	15/60	135	5.4	22/88	12/48	3/12
SCHOOL J	14	0/0	11/78	7/50	11/78	13/92	9/64	6/42	6/42	3/21	12/85	78	5.6	11/78	7/50	8/57
SCHOOL K	23	3/13	22/95	9/39	21/91	18/78	15/65	11/47	6/26	8/34	14/60	127	5.5	15/65	11/48	4/17
SCHOOL L	14	1/7	14/100	4/28	14/100	13/92	8/57	13/92	3/21	4/28	10/71	84	6.0	8/57	3/21	0/0
SCHOOL M	20	7/35	20/100	10/50	19/95	20/100	12/60	12/60	8/40	10/50	16/80	134	6.7	13/65	5/25	1/5
TOTAL	266	34/12	254/95	89/33	247/92	223/84	129/48	196/73	77/28	80/30	203/76	1532	5.8	204/76	92/34	43/16

MOMENTUM SUMMARY - CHART A (CONTINUED)

TEACHERS	28	21 / 75	28 / 100	27 / 96	27 / 96	28 / 100	24 / 86	26 / 93	25 / 89	24 / 86	27 / 96	257	9.2	3 / 11	1 / 3	2 / 7
BOX NUMBERS		1	5	8	10	11	16	18	21	22	24	TOTAL	AVER	2	14	25
SCHOOL N	20	1 / 5	17 / 85	15 / 75	19 / 95	18 / 90	8 / 40	16 / 80	4 / 20	17 / 85	15 / 75	130	6.5	8 / 40	3 / 15	1 / 5
SCHOOL P	16	0 / 0	15 / 93	5 / 31	14 / 87	14 / 87	3 / 18	15 / 93	8 / 50	4 / 25	14 / 87	92	5.7	11 / 69	2 / 12	0 / 0
SCHOOL Q	55	2 / 3	55 / 100	20 / 36	53 / 96	40 / 72	33 / 60	40 / 72	10 / 18	15 / 27	40 / 72	308	5.6	50 / 91	24 / 44	18 / 33
SCHOOL R	37	5 / 13	35 / 95	25 / 68	35 / 95	32 / 86	23 / 62	18 / 49	13 / 35	8 / 21	29 / 78	223	6.0	15 / 40	15 / 40	7 / 19
SCHOOL S	16	5 / 31	14 / 87	13 / 81	16 / 100	16 / 100	11 / 68	13 / 81	11 / 68	9 / 56	15 / 93	129	8.1	9 / 56	6 / 37	1 / 6
SCHOOL T	4	0 / 0	4 / 100	0 / 0	2 / 50	4 / 100	2 / 50	2 / 50	0 / 0	1 / 25	3 / 75	18	4.5	2 / 50	0 / 0	0 / 0
SCHOOL U	15	5 / 33	13 / 86	7 / 46	15 / 100	14 / 93	7 / 46	12 / 80	7 / 46	10 / 66	14 / 93	104	6.9	9 / 60	1 / 7	0 / 0
TOTAL	1163	18 / 11	153 / 94	85 / 52	154 / 94	138 / 85	87 / 53	116 / 71	53 / 32	64 / 39	130 / 80	1004	6.1	104 / 64	51 / 31	27 / 17
G/TOTAL	429	52 / 12	407 / 95	174 / 40	401 / 93	361 / 84	216 / 50	312 / 73	130 / 30	144 / 34	333 / 78	2536	5.9	308 / 72	143 / 33	70 / 16





KINETIC ENERGY

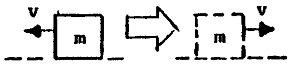
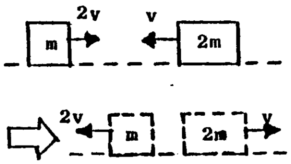
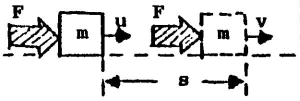
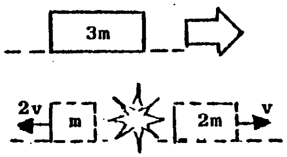
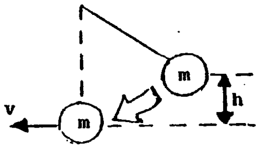
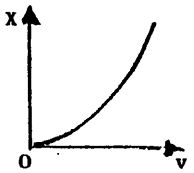
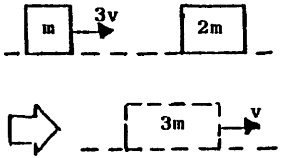
1	 Change in X = 0 2	3	4	 5 Change in X = 0
6	X is a scalar quantity 7	8	X = 20 J 9	10
11	12	 Change in X = Fs 13	 14 X is increased	15
16	17	18	 19 $X = \frac{1}{2}mv^2 = mgh$	20
21	22	For a falling body  23	24	 25 X is decreased

CHART A

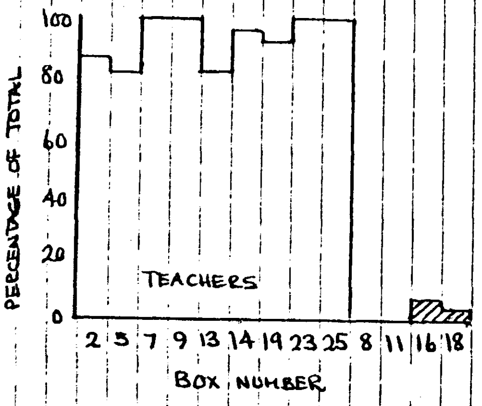
KINETIC ENERGY SUMMARY - CHART A

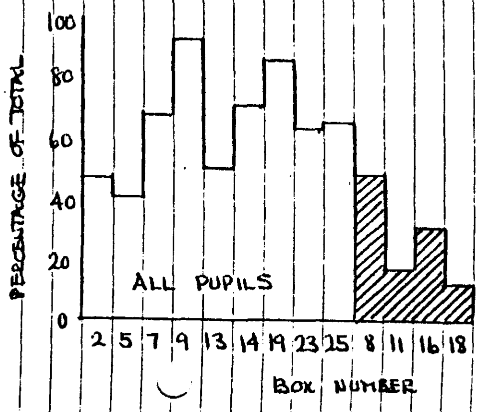
ACTUAL → / ← PERCENTAGE

TEACHERS	28	24 / 86	23 / 82	28 / 100	28 / 100	23 / 82	27 / 96	26 / 93	28 / 100	28 / 100	235	8.4	0 / 0	0 / 0	2 / 7	1 / 3
BOX NUMBERS		2	5	7	9	13	14	19	23	25	TOTAL	AVER	8	11	16	18
SCHOOL A	39	9 / 23	13 / 33	18 / 46	33 / 84	12 / 30	22 / 56	34 / 87	19 / 48	15 / 38	175	4.5	18 / 46	8 / 20	6 / 15	1 / 3
SCHOOL B	13	10 / 76	2 / 15	7 / 53	12 / 92	5 / 38	11 / 84	12 / 92	10 / 76	11 / 84	80	6.1	9 / 69	3 / 23	3 / 23	2 / 15
SCHOOL C	17	9 / 52	8 / 47	8 / 47	15 / 88	10 / 58	11 / 64	15 / 88	8 / 47	10 / 58	94	5.5	9 / 52	0 / 0	1 / 6	4 / 23
SCHOOL D	24	12 / 50	10 / 41	14 / 58	18 / 75	4 / 15	7 / 29	23 / 95	11 / 45	8 / 33	107	4.5	8 / 33	1 / 4	5 / 21	4 / 15
SCHOOL E	15	2 / 13	1 / 6	7 / 46	15 / 100	15 / 100	14 / 93	14 / 93	13 / 86	13 / 86	94	6.3	14 / 93	6 / 40	5 / 33	0 / 0
SCHOOL F	35	14 / 40	17 / 48	27 / 71	35 / 100	20 / 57	29 / 82	31 / 88	20 / 57	26 / 74	219	6.3	16 / 45	6 / 17	17 / 48	0 / 0
SCHOOL G	14	5 / 35	5 / 35	11 / 78	14 / 100	3 / 21	9 / 64	11 / 78	7 / 50	7 / 50	72	5.1	10 / 71	1 / 7	4 / 28	0 / 0
SCHOOL H	13	7 / 53	1 / 7	11 / 84	13 / 100	10 / 76	10 / 76	8 / 61	6 / 46	10 / 76	76	5.8	7 / 53	2 / 15	4 / 31	6 / 46
SCHOOL I	25	8 / 32	9 / 36	12 / 48	24 / 96	10 / 40	16 / 64	19 / 76	15 / 60	20 / 80	133	5.3	12 / 48	3 / 12	6 / 24	0 / 0
SCHOOL J	14	9 / 64	5 / 35	7 / 50	13 / 92	6 / 42	10 / 71	12 / 85	8 / 57	5 / 35	75	5.3	8 / 57	3 / 21	2 / 14	3 / 21
SCHOOL K	23	14 / 60	14 / 60	15 / 65	22 / 95	10 / 43	14 / 60	18 / 78	15 / 65	19 / 82	141	6.1	11 / 48	3 / 13	4 / 17	5 / 22
SCHOOL L	14	8 / 57	6 / 42	8 / 57	14 / 100	6 / 42	11 / 78	13 / 92	11 / 78	10 / 71	87	6.2	7 / 50	2 / 14	8 / 57	0 / 0
SCHOOL M	20	13 / 65	10 / 50	20 / 100	18 / 90	14 / 70	13 / 65	15 / 75	13 / 65	16 / 80	132	6.6	9 / 45	1 / 5	6 / 30	0 /
TOTAL	266	120 / 45	101 / 37	185 / 70	246 / 92	125 / 46	177 / 66	225 / 84	156 / 58	170 / 63	1485	5.6	138 / 52	39 / 14	71 / 27	25 / 9

KINETIC ENERGY SUMMARY – CHART A (CONTINUED)

TEACHERS	28	24/86	23/82	28/100	28/100	23/82	27/96	26/93	28/100	28/100	235	8.4	0/0	0/0	2/7	1/3
BOX NUMBERS		2	5	7	9	13	14	19	23	25	TOTAL	AVER	8	11	16	18
SCHOOL N	20	16/80	10/50	16/80	20/100	11/55	18/90	19/95	15/75	16/80	141	7.0	4/20	3/15	5/25	3/15
SCHOOL P	16	7/43	8/50	7/43	15/93	9/56	8/50	12/75	4/25	5/37	76	4.7	7/43	4/25	5/31	1/6
SCHOOL Q	55	19/34	12/21	36/65	53/96	24/43	37/67	52/94	36/65	34/61	303	5.5	29/53	15/27	12/22	6/11
SCHOOL R	37	21/57	17/46	26/70	34/92	23/62	34/92	33/89	28/76	28/76	244	6.6	13/35	6/16	10/27	8/22
SCHOOL S	16	10/62	9/56	10/62	15/93	11/68	12/75	16/100	13/81	13/81	109	6.8	6/37	5/31	3/19	3/19
SCHOOL T	4	1/25	2/50	2/50	4/100	4/100	3/75	4/100	3/75	1/25	24	6.0	2/50	1/25	3/75	0/0
SCHOOL U	15	7/46	12/80	12/80	12/80	9/60	15/100	14/93	11/73	14/93	106	7.1	6/40	2/13	4/27	1/7
TOTAL	163	81/50	70/43	109/67	153/94	91/56	127/78	150/92	110/67	111/68	1003	6.1	67/41	36/22	62/38	22/13
G/TOTAL	429	201/47	171/40	294/68	399/93	216/50	304/71	375/87	266/62	281/65	2488	5.8	205/48	75/17	133/31	47/11





POTENTIAL ENERGY

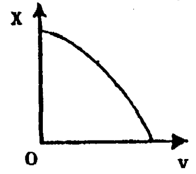
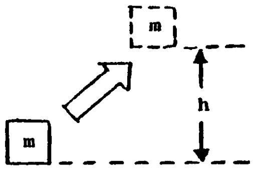
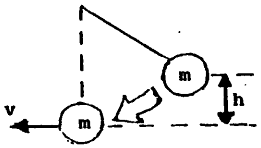
1	2	3	For a falling body  4	5
6	X is a scaler quantity 7	8	$X = 20$ J 9	10
11	12	13	14	15
16	 17 Change in X = mgh	18	 19 $X = \frac{1}{2}mv^2 = mgh$	20
21	22	23	24	25

CHART A

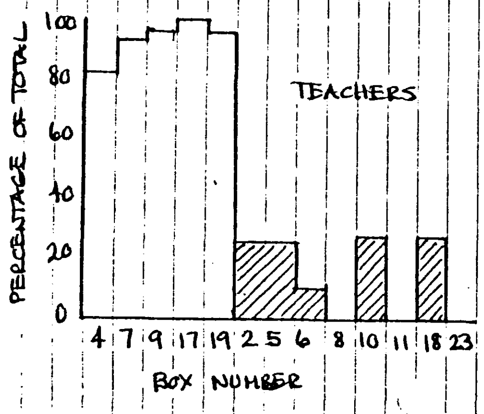
POTENTIAL ENERGY SUMMARY - CHART A

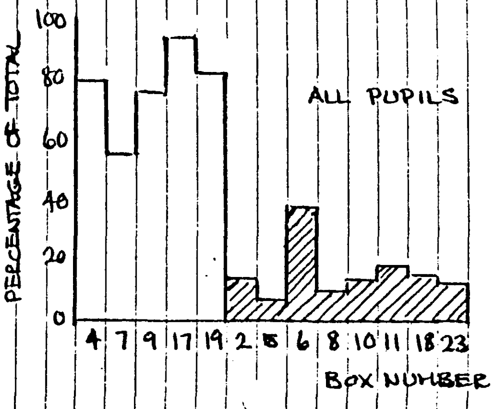
ACTUAL / PERCENTAGE

TEACHERS	28	23 / 82	26 / 93	27 / 96	28 / 100	27 / 96	131	4.7	7 / 25	7 / 25	3 / 11	0 / 0	8 / 28	0 / 0	8 / 28	0 / 0
BOX NUMBERS		4	7	9	17	19	TOTAL	AVER	2	5	6	8	10	11	18	23
SCHOOL A	39	25 / 64	15 / 38	27 / 69	35 / 89	24 / 61	126	3.2	3 / 8	1 / 3	13 / 33	7 / 18	1 / 3	3 / 8	2 / 5	13 / 33
SCHOOL B	13	11 / 84	5 / 38	8 / 61	11 / 84	8 / 61	43	3.3	2 / 15	3 / 23	2 / 15	0 / 0	0 / 0	3 / 23	1 / 8	0 / 0
SCHOOL C	17	12 / 70	7 / 41	10 / 58	15 / 88	12 / 70	56	3.3	1 / 6	1 / 6	5 / 29	3 / 18	1 / 6	0 / 0	1 / 6	3 / 18
SCHOOL D	24	19 / 79	14 / 58	16 / 66	22 / 91	18 / 75	89	3.7	4 / 17	3 / 12	12 / 50	5 / 21	1 / 4	3 / 12	1 / 4	4 / 17
SCHOOL E	15	15 / 100	4 / 27	15 / 100	14 / 93	13 / 86	61	4.1	0 / 0	0 / 0	8 / 53	0 / 0	0 / 0	5 / 33	1 / 7	0 / 0
SCHOOL F	35	25 / 71	23 / 65	30 / 85	35 / 100	29 / 82	142	4.1	2 / 6	0 / 0	14 / 40	3 / 9	5 / 14	8 / 23	8 / 23	4 / 11
SCHOOL G	14	10 / 71	10 / 71	9 / 64	13 / 92	9 / 64	51	3.6	1 / 7	4 / 28	7 / 50	2 / 14	2 / 14	2 / 14	2 / 14	3 / 21
SCHOOL H	13	13 / 100	9 / 69	11 / 84	13 / 100	11 / 84	57	4.4	2 / 15	1 / 8	1 / 8	1 / 8	2 / 15	2 / 15	2 / 15	1 / 8
SCHOOL I	25	14 / 56	10 / 40	15 / 60	23 / 92	16 / 64	78	3.1	5 / 20	4 / 16	8 / 32	5 / 20	4 / 16	1 / 4	2 / 8	5 / 20
SCHOOL J	14	7 / 50	8 / 57	7 / 50	14 / 100	10 / 71	46	3.3	0 / 0	3 / 21	6 / 43	1 / 7	2 / 14	1 / 7	3 / 21	3 / 21
SCHOOL K	23	18 / 78	9 / 39	15 / 65	23 / 100	23 / 100	88	3.8	3 / 13	2 / 9	8 / 35	5 / 22	3 / 13	2 / 9	2 / 9	3 / 13
SCHOOL L	14	12 / 85	9 / 64	11 / 78	14 / 100	11 / 78	57	4.1	1 / 7	1 / 7	2 / 14	3 / 21	2 / 14	1 / 7	2 / 14	2 / 14
SCHOOL M	20	17 / 85	10 / 50	17 / 85	20 / 100	18 / 90	82	4.1	2 / 10	0 / 0	2 / 10	0 / 0	0 / 0	6 / 30	5 / 25	1 / 0
TOTAL	266	198 / 74	133 / 50	191 / 71	252 / 94	202 / 75	976	3.7	26 / 10	23 / 9	88 / 33	35 / 13	23 / 9	37 / 14	32 / 12	42 / 16

POTENTIAL ENERGY SUMMARY - CHART A (CONTINUED)

TEACHERS	28	23/82	26/93	27/96	28/100	27/96	131	4.7	7/25	7/25	3/11	0/0	8/28	0/0	8/28	0/0
BOX NUMBERS		4	7	9	17	19	TOTAL	AVER	2	5	6	8	10	11	18	23
SCHOOL N	20	20/100	11/55	18/90	20/100	19/95	88	4.4	6/30	3/15	3/15	0/0	6/30	7/35	1/5	2/10
SCHOOL P	16	10/62	7/43	10/62	14/87	11/68	52	3.2	4/25	2/12	7/44	1/6	1/6	6/37	1/6	2/12
SCHOOL Q	55	47/85	33/60	48/87	53/96	51/92	232	4.2	3/5	3/5	16/29	3/5	3/5	12/22	6/11	4/7
SCHOOL R	37	36/97	19/51	27/73	36/97	31/84	149	4.0	13/35	1/3	1/3	1/3	11/30	10/27	14/38	3/8
SCHOOL S	16	14/87	15/93	16/100	16/100	14/87	75	4.7	7/44	0/0	2/12	0/0	7/44	1/6	7/44	0/0
SCHOOL T	4	4/100	3/75	4/100	4/100	4/100	19	4.8	0/0	0/0	1/25	0/0	0/0	1/25	0/0	0/0
SCHOOL U	15	11/73	12/80	13/86	15/100	10/66	61	4.1	3/20	0/0	2/13	1/7	3/20	2/13	2/13	0/0
TOTAL	163	142/87	100/61	136/83	158/97	150/92	676	4.1	36/22	9/5	32/20	6/4	31/19	39/24	31/19	11/7
G/TOTAL	429	340/79	233/54	327/76	410/95	352/82	1652	3.8	62/14	32/7	120/28	41/10	54/13	76/18	63/15	53/12





FORCE

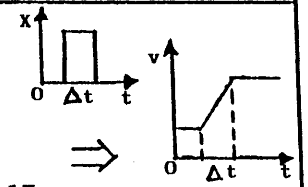
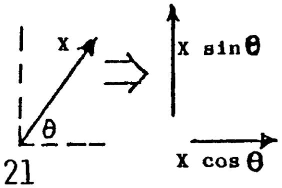
1	2	$X = 20$ N 3	4	5
For a falling body $X = mg$ 6	7	8	9	10
X is a vector quantity 11	$\dot{X} = \frac{d(mv)}{dt}$ 12	13	14	 15
16	17	18	19	20
 21	22	23	24	25

CHART A

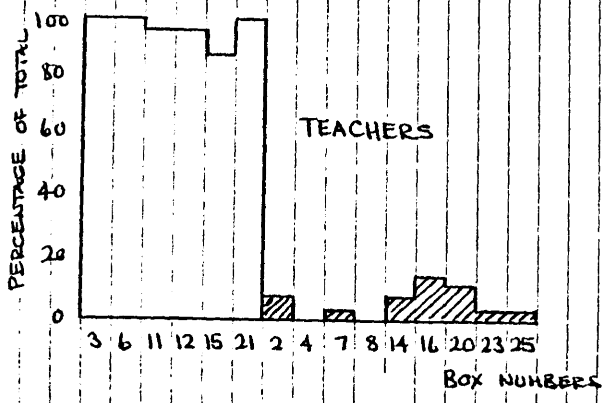
FORCE SUMMARY - CHART A

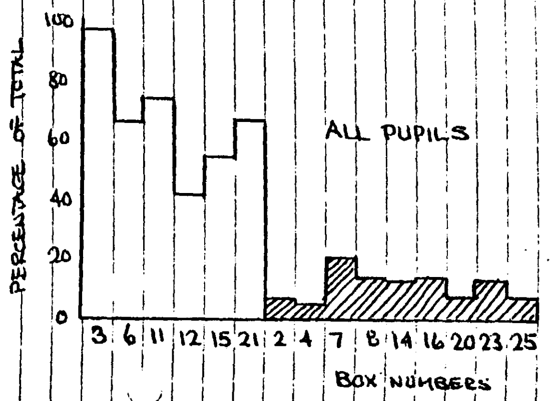
ACTUAL → upper left / PERCENTAGE → lower right

TEACHERS	28	28 / 100	28 / 100	27 / 96	27 / 96	24 / 86	28 / 100	162	5.8	2 / 7	0 / 0	1 / 3	0 / 0	2 / 7	4 / 14	3 / 11	1 / 3	1 / 3
BOX NUMBERS		3	6	11	12	15	21	TOTAL	AVER	2	4	7	8	14	16	20	23	25
SCHOOL A	39	39 / 100	21 / 53	24 / 61	11 / 28	13 / 33	28 / 71	136	3.5	0 / 0	4 / 10	9 / 23	2 / 5	1 / 3	4 / 10	3 / 8	1 / 3	3 / 8
SCHOOL B	13	13 / 100	9 / 69	8 / 61	6 / 46	6 / 46	11 / 84	53	4.1	0 / 0	0 / 0	5 / 38	2 / 15	0 / 0	5 / 38	1 / 8	1 / 8	1 / 8
SCHOOL C	17	16 / 94	10 / 58	3 / 17	7 / 41	10 / 58	5 / 29	51	3.0	4 / 24	0 / 0	4 / 24	2 / 12	1 / 6	3 / 18	2 / 12	2 / 12	2 / 12
SCHOOL D	24	22 / 92	12 / 50	12 / 50	4 / 17	6 / 25	8 / 33	64	2.7	0 / 0	1 / 4	9 / 37	3 / 12	5 / 21	3 / 12	6 / 25	6 / 25	2 / 8
SCHOOL E	15	15 / 100	7 / 46	12 / 80	9 / 60	12 / 80	15 / 100	70	4.7	0 / 0	0 / 0	1 / 7	0 / 0	0 / 0	0 / 0	0 / 0	1 / 7	1 / 7
SCHOOL F	35	33 / 94	29 / 65	27 / 77	19 / 54	15 / 42	21 / 60	138	3.9	0 / 0	4 / 11	6 / 17	12 / 34	4 / 11	5 / 14	1 / 3	8 / 23	0 / 0
SCHOOL G	14	13 / 92	10 / 71	9 / 64	4 / 28	8 / 57	4 / 28	48	3.4	2 / 14	0 / 0	4 / 28	4 / 28	5 / 36	4 / 28	1 / 7	0 / 0	2 / 14
SCHOOL H	13	13 / 100	12 / 92	10 / 76	5 / 38	9 / 69	12 / 92	61	4.7	0 / 0	0 / 0	1 / 8	1 / 8	1 / 8	2 / 15	1 / 8	2 / 15	0 / 0
SCHOOL I	25	24 / 96	15 / 60	18 / 72	3 / 12	12 / 48	13 / 52	85	3.4	2 / 8	0 / 0	4 / 16	1 / 4	5 / 20	2 / 4	5 / 20	0 / 0	0 / 0
SCHOOL J	14	14 / 100	8 / 57	11 / 78	1 / 7	7 / 50	8 / 57	49	3.5	2 / 14	1 / 7	4 / 28	2 / 14	1 / 7	0 / 0	2 / 14	1 / 7	1 / 7
SCHOOL K	23	22 / 95	13 / 56	16 / 69	9 / 39	8 / 34	16 / 69	84	3.6	4 / 17	2 / 9	6 / 26	3 / 13	2 / 9	1 / 4	3 / 13	2 / 9	1 / 4
SCHOOL L	14	12 / 85	11 / 78	12 / 85	6 / 42	6 / 42	10 / 71	57	4.1	1 / 7	1 / 7	0 / 0	1 / 7	2 / 14	0 / 0	1 / 7	1 / 7	1 / 7
SCHOOL M	20	20 / 100	18 / 90	19 / 95	16 / 80	11 / 55	17 / 85	101	5.0	1 / 5	1 / 5	1 / 5	0 / 0	0 / 0	4 / 20	2 / 10	3 / 15	1 / 5
TOTAL	266	256 / 96	169 / 63	181 / 68	100 / 37	123 / 46	168 / 63	997	3.7	16 / 6	14 / 5	54 / 20	33 / 12	27 / 10	33 / 12	28 / 10	28 / 10	15 / 6

FORCE SUMMARY - CHART A (CONTINUED)

TEACHERS	28	28 / 100	28 / 100	27 / 96	27 / 96	24 / 86	28 / 100	162	5.8	2 / 7	0 / 0	1 / 3	0 / 0	2 / 7	4 / 14	3 / 11	1 / 3	1 / 3
BOX NUMBERS		3	6	11	12	15	21	TOTAL	AVER	2	4	7	8	14	16	20	23	25
SCHOOL N	20	19 / 95	15 / 75	17 / 85	19 / 95	13 / 65	14 / 70	97	4.8	2 / 10	0 / 0	2 / 10	2 / 10	4 / 20	2 / 10	1 / 5	3 / 15	3 / 15
SCHOOL P	16	15 / 93	6 / 37	13 / 81	5 / 31	8 / 50	7 / 43	54	3.4	1 / 6	3 / 19	3 / 19	6 / 37	2 / 12	1 / 6	0 / 0	5 / 31	4 / 25
SCHOOL Q	55	54 / 98	32 / 58	48 / 87	13 / 29	32 / 58	45 / 81	224	4.1	5 / 9	1 / 2	7 / 13	11 / 20	8 / 15	9 / 16	2 / 4	10 / 18	5 / 9
SCHOOL R	37	36 / 97	34 / 92	29 / 78	16 / 43	27 / 73	32 / 86	174	4.7	4 / 11	1 / 3	8 / 22	4 / 11	7 / 19	7 / 19	1 / 3	6 / 16	3 / 8
SCHOOL S	16	16 / 100	11 / 68	15 / 93	13 / 81	12 / 75	10 / 62	77	4.8	3 / 19	2 / 12	1 / 6	1 / 6	4 / 25	6 / 37	1 / 6	3 / 19	2 / 12
SCHOOL T	4	4 / 100	4 / 100	2 / 50	4 / 100	3 / 75	3 / 75	20	5.0	0 / 0	0 / 0	2 / 50	2 / 50	2 / 50	0 / 0	1 / 25	0 / 0	1 / 25
SCHOOL U	15	15 / 100	9 / 60	8 / 53	8 / 53	10 / 66	9 / 60	59	3.9	1 / 7	2 / 13	7 / 47	1 / 7	2 / 13	0 / 0	1 / 7	3 / 20	1 / 7
TOTAL	163	159 / 97	111 / 68	132 / 81	78 / 48	105 / 64	120 / 74	705	4.3	16 / 10	9 / 5	30 / 18	27 / 16	29 / 18	25 / 15	7 / 4	30 / 18	19 / 12
G/TOTAL	429	415 / 97	280 / 65	313 / 73	178 / 41	228 / 53	288 / 66	1702	4.0	32 / 7	23 / 5	84 / 20	60 / 14	56 / 13	62 / 14	35 / 8	58 / 13	34 / 8





IMPULSE

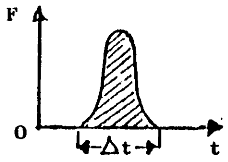
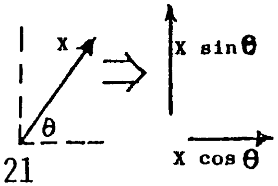
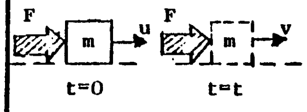
 1 X = shaded area	2	3	4	5
6	7	8	9	10
X is a vector quantity 11	12	13	14	15
16	17	18	19	X = 20 N s 20
 21	 Change in X = Ft 22	23	$X = 20 \text{ kg m s}^{-1}$ 24	25

CHART A

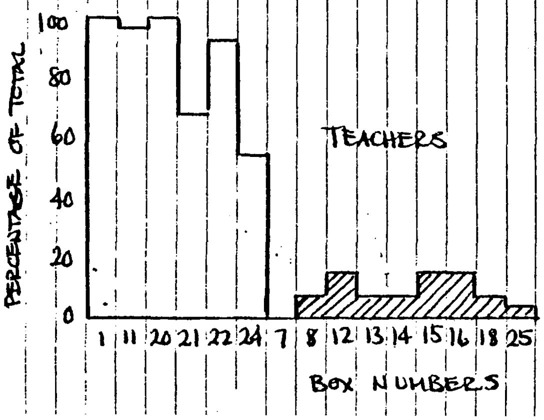
IMPULSE SUMMARY - CHART A

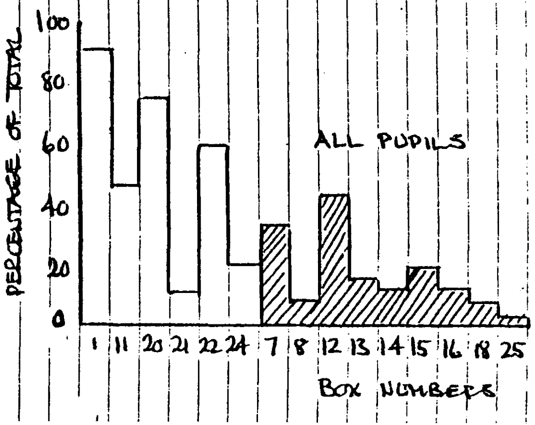
ACTUAL → / ← PERCENTAGE

TEACHERS	28	28 / 100	27 / 96	28 / 100	19 / 68	26 / 93	15 / 54	143	5.1	0 / 0	2 / 7	4 / 14	2 / 7	2 / 7	4 / 14	4 / 14	2 / 7	1 / 4
BOX NUMBERS		1	11	20	21	22	24	TOTAL	AVER	7	8	12	13	14	15	16	18	25
SCHOOL A	39	27 / 69	12 / 30	30 / 76	1 / 2	20 / 51	3 / 7	93	2.4	9 / 23	5 / 13	23 / 59	10 / 26	1 / 2	4 / 10	5 / 13	0 / 0	4 / 10
SCHOOL B	13	13 / 100	6 / 46	10 / 76	3 / 23	7 / 53	2 / 15	41	3.2	6 / 46	1 / 8	2 / 15	4 / 31	2 / 15	2 / 15	2 / 15	0 / 0	0 / 0
SCHOOL C	17	16 / 94	4 / 23	9 / 52	1 / 5	9 / 52	3 / 17	42	2.5	8 / 47	0 / 0	3 / 18	2 / 12	4 / 24	8 / 47	3 / 18	0 / 0	2 / 12
SCHOOL D	24	21 / 87	11 / 45	13 / 54	4 / 16	11 / 45	2 / 8	62	2.6	11 / 45	0 / 0	18 / 75	4 / 16	6 / 25	5 / 21	2 / 8	5 / 21	3 / 12
SCHOOL E	15	15 / 100	1 / 6	15 / 100	0 / 0	15 / 100	4 / 26	50	3.3	10 / 67	0 / 0	6 / 40	0 / 0	0 / 0	1 / 7	0 / 0	0 / 0	0 / 0
SCHOOL F	35	34 / 97	23 / 65	26 / 74	1 / 2	23 / 65	6 / 17	113	3.2	10 / 29	3 / 8	19 / 54	3 / 8	3 / 8	8 / 23	8 / 23	2 / 5	1 / 2
SCHOOL G	14	11 / 78	4 / 28	12 / 85	0 / 0	9 / 64	1 / 7	37	2.6	5 / 36	1 / 7	8 / 57	7 / 50	1 / 7	1 / 7	1 / 7	1 / 7	0 / 0
SCHOOL H	13	12 / 92	7 / 53	9 / 63	1 / 7	6 / 46	1 / 7	36	2.7	5 / 38	0 / 0	6 / 46	0 / 0	1 / 7	4 / 31	4 / 31	2 / 15	0 / 0
SCHOOL I	25	18 / 72	7 / 28	11 / 44	2 / 8	17 / 68	7 / 28	62	2.5	7 / 28	3 / 12	11 / 44	6 / 24	3 / 12	3 / 12	0 / 0	2 / 8	1 / 4
SCHOOL J	14	12 / 85	5 / 35	11 / 78	1 / 7	8 / 57	0 / 0	37	2.6	4 / 28	0 / 0	5 / 35	1 / 7	1 / 7	3 / 21	0 / 0	1 / 7	1 / 7
SCHOOL K	23	21 / 91	12 / 52	15 / 65	4 / 17	13 / 56	9 / 39	74	3.2	7 / 30	4 / 17	8 / 35	4 / 17	2 / 9	6 / 26	0 / 0	3 / 13	3 / 13
SCHOOL L	14	13 / 92	10 / 71	12 / 85	1 / 7	6 / 42	2 / 14	44	3.1	0 / 0	1 / 7	7 / 50	3 / 21	2 / 14	2 / 14	1 / 7	1 / 7	0 / 0
SCHOOL M	20	19 / 95	16 / 80	16 / 80	4 / 20	9 / 45	6 / 30	70	3.5	0 / 0	3 / 15	8 / 40	2 / 10	4 / 20	2 / 10	3 / 15	6 / 30	0 / 0
TOTAL	266	232 / 87	118 / 44	189 / 71	23 / 8	153 / 57	46 / 17	761	2.9	82 / 31	21 / 8	124 / 47	46 / 17	30 / 11	49 / 18	29 / 11	23 / 9	15 / 6

IMPULSE SUMMARY – CHART A (CONTINUED)

TEACHERS	28	28 / 100	27 / 96	28 / 100	19 / 68	26 / 93	15 / 54	143	5.1	0 / 0	2 / 7	4 / 14	2 / 7	2 / 7	4 / 14	4 / 14	2 / 7	1 / 4
BOX NUMBERS		1	11	20	21	22	24	TOTAL	AVER	7	8	12	13	14	15	16	18	25
SCHOOL N	20	20 / 100	10 / 50	18 / 90	3 / 15	7 / 35	8 / 40	66	3.3	9 / 45	0 / 0	1 / 5	2 / 10	3 / 15	3 / 15	4 / 20	1 / 5	0 / 0
SCHOOL P	16	16 / 100	5 / 31	11 / 68	2 / 12	11 / 68	1 / 6	46	2.9	9 / 56	0 / 0	5 / 31	3 / 19	1 / 6	1 / 6	1 / 6	0 / 0	2 / 12
SCHOOL Q	55	52 / 94	28 / 50	50 / 90	5 / 9	35 / 63	11 / 20	181	3.3	14 / 25	3 / 5	27 / 49	17 / 31	9 / 16	17 / 31	8 / 14	1 / 2	2 / 4
SCHOOL R	37	36 / 97	18 / 49	30 / 81	8 / 21	28 / 76	8 / 21	128	3.5	12 / 32	7 / 19	13 / 35	2 / 5	6 / 16	7 / 19	5 / 13	2 / 5	3 / 8
SCHOOL S	16	16 / 100	13 / 81	15 / 93	5 / 31	9 / 56	7 / 43	65	4.1	4 / 25	8 / 50	4 / 25	1 / 6	2 / 12	2 / 12	4 / 25	3 / 19	1 / 6
SCHOOL T	4	4 / 100	4 / 100	4 / 100	0 / 0	3 / 75	2 / 50	17	4.2	0 / 0	1 / 25	3 / 75	0 / 0	0 / 0	0 / 0	3 / 75	0 / 0	0 / 0
SCHOOL U	15	13 / 86	4 / 26	14 / 93	1 / 6	6 / 40	3 / 20	41	2.7	7 / 47	0 / 0	8 / 53	2 / 13	3 / 20	4 / 26	0 / 0	3 / 20	0 / 0
TOTAL	1163	157 / 96	82 / 50	142 / 87	24 / 15	99 / 61	40 / 24	544	3.3	55 / 34	19 / 12	61 / 37	27 / 17	24 / 15	34 / 21	25 / 15	10 / 6	8 / 5
G/TOTAL	429	389 / 91	200 / 47	331 / 77	47 / 11	252 / 59	86 / 20	1305	3.0	137 / 32	40 / 9	185 / 43	73 / 17	54 / 12	83 / 19	54 / 12	33 / 8	23 / 5





APPENDIX L

		'VALID' RESPONSES					TOTAL VALID	OTHER RESPONSES				TOTAL ALL	CONFIDENCE RATING				
		MOMENTUM	K.E.	P.E.	WEIGHT	DENSITY		FORCE	IMPULSE	ACC'N	OTHER		1	2	3	4	5
SCHOOL A	N=39	30	24	21	14	8	97	19	4	3	3	126	0	4	17	14	4
SCHOOL B	N=13	11	11	11	3	1	37	8	2	2	3	52	2	2	6	2	1
SCHOOL C	N=17	5	7	3	4	0	19	7	2	2	4	34	1	0	6	7	3
SCHOOL D	N=24	18	19	10	4	3	54	7	1	4	3	69	1	3	15	3	2
SCHOOL E	N=15	10	12	12	1	7	42	11	1	1	2	57	1	1	11	1	1
SCHOOL F	N=35	27	21	21	8	6	83	21	4	1	5	114	0	4	20	8	3
SCHOOL G	N=14	7	12	8	2	3	32	5	2	0	1	40	0	4	7	2	1
SCHOOL H	N=13	10	8	8	3	1	30	4	1	1	1	37	0	4	6	3	0
SCHOOL I	N=25	14	8	11	4	3	40	13	0	1	3	57	0	6	12	5	2
SCHOOL J	N=14	3	3	2	3	0	11	6	0	1	3	21	0	3	7	2	2
TOTAL	209	135	125	107	46	32	445	101	17	16	28	607	5	31	107	47	19

RESULTS FROM PAGE 5 OF TEST BOOKLET

In Appendix L, the confidence rating totals do not always exactly tally from one table to the next. This slight anomaly results from:

(i) some pupils failing to fully complete this part;

(ii) a few pupils failing to follow instructions.

		'VALID' RESPONSES					TOTAL	OTHER RESPONSES				TOTAL	CONFIDENCE RATING				
		MOMENTUM	K.E.	P.E.	WEIGHT	DENSITY	VALID	FORCE	IMPULSE	ACC'N	OTHER	ALL	1	2	3	4	5
SCHOOL K	N=23	16	16	13	9	1	55	7	3	4	8	77	3	3	11	4	2
SCHOOL L	N=14	12	8	8	3	1	32	5	0	1	1	39	0	2	4	7	1
SCHOOL M	N=20	12	12	10	2	0	36	14	4	0	3	57	0	1	14	2	3
SCHOOL N	N=20	16	14	15	6	5	56	7	4	1	8	76	0	2	10	4	4
SCHOOL P	N=16	10	8	6	5	2	31	7	0	0	1	39	1	2	6	1	6
SCHOOL Q	N=55	38	26	28	12	4	108	22	1	3	7	141	1	8	32	8	6
SCHOOL R	N=37	32	24	24	13	5	98	14	4	3	5	124	0	7	12	9	9
SCHOOL S	N=16	12	11	11	8	2	44	8	6	0	1	59	0	5	5	5	1
SCHOOL T	N=4	2	2	1	1	1	7	4	1	0	2	14	0	1	2	1	0
SCHOOL U	N=15	8	5	4	5	0	22	5	0	0	0	27	0	4	8	1	2
TOTAL	220	158	126	120	64	21	489	93	23	12	36	653	5	35	104	42	34
GRAND TOTAL	429	293	251	227	110	53	934	194	40	28	64	1260	10	66	211	89	53
PERCENTAGE	100	68	59	53	26	12		45	9	7	15		2	15	49	21	12

RESULTS FROM PAGE 5 OF TEST BOOKLET (CONTINUED)

		'VALID' RESPONSES				TOTAL VALID	OTHER RESPONSES			TOTAL ALL	CONFIDENCE RATING			
		K.E.	P.E.	ENERGY	WORK DONE		MOMENTUM	FORCE	OTHER		1	2	3	4
SCHOOL A	N=39	22	10	1	1	34	9	1	2	46	7	14	13	5
SCHOOL B	N=13	8	1	0	1	10	2	0	2	14	3	3	6	1
SCHOOL C	N=17	5	0	2	0	7	1	4	4	16	5	3	8	0
SCHOOL D	N=24	11	2	0	1	14	7	7	0	28	7	11	2	4
SCHOOL E	N=15	14	2	0	0	16	1	0	1	18	0	4	10	1
SCHOOL F	N=35	22	21	6	7	56	2	3	2	63	6	9	11	9
SCHOOL G	N=14	10	1	0	0	11	4	0	1	16	6	4	3	0
SCHOOL H	N=13	4	7	2	0	13	2	0	0	15	6	4	3	0
SCHOOL I	N=25	6	13	0	0	19	6	1	3	29	9	7	8	1
SCHOOL J	N=14	3	0	0	0	3	7	2	4	16	9	3	2	0
TOTAL	209	105	57	11	10	183	41	18	19	261	58	62	66	21

RESULTS FROM PAGE 8 OF TEST BOOKLET

		'VALID'	RESPONSES			TOTAL	OTHER	RESPONSES		TOTAL	CONFIDENCE	RATING		
		K.E.	P.E.	ENERGY	WORK DONE	VALID	MOMENTUM	FORCE	OTHER	ALL	1	2	3	4
SCHOOL K	N=23	11	5	1	0	17	4	5	2	28	6	11	5	1
SCHOOL L	N=14	9	3	3	0	15	2	1	0	18	2	4	5	3
SCHOOL M	N=20	16	1	0	0	17	1	0	2	20	2	8	8	1
SCHOOL N	N=20	15	5	1	1	22	1	0	1	24	1	8	8	3
SCHOOL P	N=16	14	0	0	0	14	0	1	0	15	2	5	7	2
SCHOOL Q	N=55	26	9	4	5	44	9	6	2	61	13	25	15	0
SCHOOL R	N=37	25	5	1	0	31	5	2	4	42	13	8	10	6
SCHOOL S	N=16	4	8	4	2	18	0	2	0	20	3	7	4	2
SCHOOL T	N=4	2	0	0	0	2	0	2	0	4	0	1	2	1
SCHOOL U	N=15	7	3	0	0	10	6	0	0	16	1	6	7	1
TOTAL	220	129	39	14	8	190	28	19	11	248	43	83	71	20
GRAND TOTAL	429	234	96	25	18	373	69	36	30	509	101	145	137	41
PERCENTAGE	100	55	22	6	4		16	8	7		24	34	32	10

RESULTS FROM PAGE 8 OF TEST BOOKLET (CONTINUED)

		'VALID' RESPONSES				TOTAL	OTHER RESPONSES			TOTAL	CONFIDENCE RATING			
		K.E.	P.E.	ENERGY	WORK DONE	VALID	MOMENTUM	FORCE	OTHER	ALL	1	2	3	4
SCHOOL A	N = 21	8	7	0	0	15	5	1	3	24	4	9	7	1
SCHOOL B	N = 6	4	0	0	0	4	1	0	1	6	2	1	3	0
SCHOOL C	N = 10	5	1	1	0	7	1	1	1	10	0	5	5	0
SCHOOL D	N = 19	11	3	0	0	14	1	6	2	23	4	9	5	1
SCHOOL E	N = 4	2	1	0	0	3	1	0	0	4	0	2	1	1
SCHOOL F	N = 16	12	7	0	1	20	1	0	0	21	1	7	6	2
SCHOOL G	N = 12	11	1	0	0	12	0	0	1	13	3	7	2	0
SCHOOL H	N = 10	4	6	0	0	10	0	0	2	12	3	5	2	0
SCHOOL I	N = 15	8	6	0	0	14	1	1	0	16	2	8	5	0
SCHOOL J	N = 12	3	2	1	2	8	0	2	4	14	3	7	2	0
TOTAL	125	68	34	2	3	107	11	11	14	143	22	60	38	5

RESULTS FROM PAGE 9 OF TEST BOOKLET

		'VALID' RESPONSES				TOTAL	OTHER RESPONSES			TOTAL	CONFIDENCE RATING			
		K.E.	P.E.	ENERGY	WORK DONE	VALID	MOMENTUM	FORCE	OTHER	ALL	1	2	3	4
SCHOOL K	N = 17	9	3	0	0	12	0	1	4	17	5	5	5	2
SCHOOL L	N = 6	3	1	2	0	6	0	0	0	6	0	3	3	0
SCHOOL M	N = 11	9	2	1	0	12	0	1	0	13	1	7	1	1
SCHOOL N	N = 10	6	1	1	0	8	0	0	3	11	0	7	0	3
SCHOOL P	N = 7	4	1	0	0	5	0	0	2	7	2	2	0	3
SCHOOL Q	N = 37	21	13	3	4	43	0	0	0	43	8	12	13	4
SCHOOL R	N = 21	17	1	1	0	19	2	2	1	24	6	6	7	2
SCHOOL S	N = 10	4	6	0	0	10	0	1	0	11	1	4	5	0
SCHOOL T	N = 1	0	0	0	0	0	0	1	0	1	0	0	1	0
SCHOOL U	N = 7	5	3	0	0	8	0	0	1	9	2	1	4	0
TOTAL	127	78	31	8	4	123	2	6	11	142	25	47	39	15
GRAND TOTAL	252	146	65	10	7	230	13	17	25	285	47	107	77	20
PERCENTAGE	100	58	26	4	3		5	7	10		19	42	31	8

RESULTS FROM PAGE 9 OF TEST BOOKLET (CONTINUED)

		QUESTION USED						QUANTITY X IS						EQUATION		UNITS		OTHER FACTS		
		1	2	3	4	5	OWN	MOMENTUM	K.E.	P.E.	ENERGY	FORCE	OTHER	YES	NO	YES	NO	2	1	0
SCHOOL A	N=32	0	16	7	6	4	8	2	25	3	1	0	1	30	2	31	1	13	9	10
SCHOOL B	N=10	1	2	2	1	2	2	1	6	1	0	0	1	7	2	8	1	3	3	3
SCHOOL C	N=12	2	3	3	2	3	2	0	9	1	1	0	1	11	0	11	1	5	1	4
SCHOOL D	N=17	2	3	2	5	3	6	0	12	1	0	2	1	14	0	14	2	3	3	6
SCHOOL E	N=13	0	5	3	3	0	3	0	13	0	0	0	0	13	0	13	0	7	1	1
SCHOOL F	N=26	1	11	6	4	4	4	0	21	4	1	0	0	25	1	25	1	13	3	10
SCHOOL G	N=13	2	3	2	3	3	1	1	12	0	0	0	0	11	2	11	2	4	2	7
SCHOOL H	N=11	0	3	5	2	1	1	0	10	1	0	0	0	11	0	11	0	4	1	6
SCHOOL I	N=19	0	2	7	4	6	6	2	11	6	0	0	0	15	4	16	3	2	7	10
SCHOOL J	N=12	3	3	2	1	3	0	0	8	1	0	0	2	10	1	11	0	3	5	3
TOTAL	165	11	51	39	31	29	33	6	127	18	3	2	6	147	12	151	11	57	35	60

RESULTS FROM PAGES 10/11 OF TEST BOOKLET

		QUESTION USED						QUANTITY X IS						EQUATION		UNITS		OTHER FACTS		
		1	2	3	4	5	OWN	MOMENTUM	K.E.	P.E.	ENERGY	FORCE	OTHER	YES	NO	YES	NO	2	1	0
SCHOOL K	N = 15	2	6	2	3	6	3	0	10	2	1	1	0	14	1	15	0	6	2	7
SCHOOL L	N = 11	1	3	1	3	1	3	0	9	0	1	1	0	11	0	10	1	4	3	4
SCHOOL M	N = 17	0	1	15	0	0	1	0	17	0	0	0	0	16	1	16	1	2	9	6
SCHOOL N	N = 18	1	3	5	3	2	1	0	15	2	0	0	0	17	0	13	4	5	6	6
SCHOOL P	N = 13	1	1	2	8	0	1	1	12	0	0	0	0	12	1	13	0	5	3	5
SCHOOL Q	N = 35	0	10	3	17	8	7	1	29	3	0	0	2	31	4	31	4	4	5	26
SCHOOL R	N = 27	3	1	7	8	5	5	0	21	2	2	0	1	24	2	24	2	10	8	8
SCHOOL S	N = 11	0	1	2	2	3	7	0	5	3	3	0	0	9	2	11	0	2	0	9
SCHOOL T	N = 4	1	2	0	2	1	1	0	3	1	0	0	0	4	0	4	0	0	2	2
SCHOOL U	N = 11	0	5	4	1	1	0	1	6	3	1	0	0	10	1	11	0	3	4	4
TOTAL	162	9	33	41	47	27	29	3	127	16	8	2	3	148	12	148	12	41	42	77
GRAND TOTAL	327	20	84	80	78	56	82	9	254	34	11	4	9	295	24	299	23	98	77	131
PERCENTAGE	100	6	26	24	24	17	25	3	78	10	3	1	3	90	7	91	7	30	24	42

RESULTS FROM PAGES 10/11 OF TEST BOOKLET (CONTINUED)

		QUANTITY X IS						EQUATION		UNITS		OTHER FACTS		
		MOMENTUM	K.E.	P.E.	ENERGY	FORCE	OTHER	YES	NO	YES	NO	2	1	0
SCHOOL A	N=7	1	2	4	0	0	0	5	2	7	0	1	3	3
SCHOOL B	N=3	0	3	0	0	0	0	3	0	3	0	0	3	0
SCHOOL C	N=5	0	3	1	0	1	0	5	0	5	0	1	2	1
SCHOOL D	N=7	0	4	1	0	1	1	7	0	5	0	1	0	2
SCHOOL E	N=2	0	0	2	0	0	0	2	0	2	0	0	0	1
SCHOOL F	N=9	1	7	1	0	0	0	9	0	8	1	4	1	4
SCHOOL G	N=1	0	1	0	0	0	0	1	0	1	0	0	0	1
SCHOOL H	N=2	0	1	1	0	0	0	2	0	2	0	0	1	1
SCHOOL I	N=5	0	2	2	0	1	0	5	0	5	0	0	0	5
SCHOOL J	N=2	0	1	0	0	0	1	2	0	1	1	0	0	2
TOTAL	43	2	24	12	0	3	2	41	2	39	2	7	10	20

RESULTS FROM PAGE 12 OF TEST BOOKLET

		QUANTITY X IS						EQUATION		UNITS		OTHER FACTS		
		MOMENTUM	K.E.	P.E.	ENERGY	FORCE	OTHER	YES	NO	YES	NO	2	1	0
SCHOOL K	N = 8	0	6	2	0	0	0	8	0	8	0	3	2	3
SCHOOL L	N = 3	0	2	0	1	0	0	1	2	3	0	0	2	1
SCHOOL M	N = 2	0	1	0	0	0	1	2	0	2	0	0	1	1
SCHOOL N	N = 2	0	2	0	0	0	0	2	0	2	0	1	0	1
SCHOOL P	N = 3	0	2	1	0	0	0	3	0	3	0	3	0	0
SCHOOL Q	N = 16	0	9	4	0	0	3	15	1	16	0	2	8	6
SCHOOL R	N = 7	0	7	0	0	0	0	7	0	7	0	3	0	4
SCHOOL S	N = 5	0	2	2	1	0	0	5	0	4	1	1	1	3
SCHOOL T	N = 0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCHOOL U	N = 4	0	4	1	0	0	0	4	0	2	2	2	1	1
TOTAL	50	0	35	10	2	0	4	47	3	47	3	15	15	20
GRAND TOTAL	93	2	59	22	2	3	6	88	5	86	5	22	25	40
PERCENTAGE	100	2	63	24	2	3	6	95	5	92	5	24	27	43

RESULTS FROM PAGE 12 OF TEST BOOKLET (CONTINUED)