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STUDENT PRECONCEPTIONS IN INTRODUCTORY HIGH SCHOOL PHYSICS

by



PAMELA LAMBERT

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## Abstract

The purpose of this study was to discover the nature and extent of preconceptions in the area of Newton's First and Second Laws of Motion held by students in Physics 10 classes in Edmonton Public Schools before beginning instruction in the subject.

Forty students were randomly selected from beginning physics classes in four Edmonton Public High Schools. Individual interviews in which the students were presented with four tasks were tape-recorded and later transcribed. Three tasks represented examples of Newton's First Law of Motion, the fourth demonstrated the Second Law. A criterion test based on these laws was devised and set to the students in their regular classes at the end of the semester. The end-of-term marks assessed by the physics teachers at the end of the semester were also collected.

~~The transcriptions or protocols were analysed for the preconceptions expressed by the students; from these, student profiles were obtained and frequency tables of conceptions used were drawn up. The profiles were used to assess cognitive stages for each student on each task in order to compare the replies of the students on the four tasks and to compare performance on these tasks with achievement on the criterion test and in the school-assessed end-of-term marks.~~

It was found that on each task, a little over one third of the students were in the stage of formal operations as

expressed by possession of the concept of conservation of motion or by perception of motion relative to an external frame of reference. There was some agreement between performance on the tasks involving Newton's First Law of Motion significant at the 0.05 level, but no significant agreement between these tasks and the fourth, on Newton's Second Law of Motion.

There was also agreement between success on the first three tasks and achievement on the criterion test significant at the .01 level but no significant correlation with end-of-term marks or with performance on the fourth task.

Few students consistently conserved motion; the numbers doing so depended to some extent on the nature of the task.

Many of the preconceptions expressed resembled ideas held by ancient philosophers especially Aristotle. Some such ideas were of self-expanding motion and the role played by air currents in sustaining or preventing motion which were similar to ideas held by early philosophers, especially Aristotle. It was thought that different physical laws applied to space from earth - an idea held also by Aristotle.

The influence of space science was perceived. Most students were aware that there was no air in space. Many students were confused by the term "weightlessness". Little understanding was found or expected about orbits except from boys who were particularly interested.

Most students understood that gravity was a force of attraction to the earth but never-the-less, at least half of the students used it at some time to explain inertia of a stationary or a moving body. The vertical force of gravity was also thought to retard horizontal motion.

There was a significant gender difference in the use of primitive concepts on the tasks. Girls tended to perform at a lower level than boys in each task. Girls scored significantly better in end-of-term marks, ( $p < 0.05$ ), but there was no significant difference on the criterion test where boys tended to achieve better marks.

It is suggested that teachers should bear in mind these specific preconceptions of students particularly the use of gravity as a stabilising factor and as an opposition to horizontal motion. Also clear definitions of elementary terms such as friction would help some students unfamiliar with mechanics. Neither perception of relative motion nor conservation of motion should be taken for granted.



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## Chapter I

### THE PROBLEM

#### A. Introduction

A significant factor in the teaching of many school subjects is that students come to most learning situations with some previously formed ideas about the topic (Driver and Easley, 1978). This is true of all science subjects and particularly of physics. These preconceptions can interfere with the learning process in the student if the teacher is unaware of their presence or form. If on the other hand, he is conscious of their probable existence and the characteristics of the most prevalent beliefs, the teacher can use them with great effect as will be described later.

That there should be a disparity between the child's interpretation of the physical world and that accepted by physicists is not surprising when we remember that the present state of our understanding in physics has been built up by many philosophers and scientists over hundreds of years. The contribution of each thinker often represents a lifetime's work which has been absorbed into and has modified a complicated, coherent framework of knowledge which interprets practically all that is known so far in the physical world. This is part of what Kuhn calls a "paradigm" (Kuhn, 1962).



Now, the student has, before entering the science classroom, also experienced and analysed his limited environment. He has built up his own logical framework of knowledge which appears in his mind to be in harmony with his surroundings (Driver, 1973). According to Polanyi this logical framework is not acquired passively but is adopted with a strong commitment. It directs the student's attention to selected stimuli and determines his interpretation of any problem that he encounters. Polanyi calls this "Personal Knowledge" (Polanyi, 1958). The student's framework of knowledge will probably not compare with the publicly accepted framework of knowledge in physics in its scope and may be actually inconsistent with it, yet it cannot necessarily be called "incorrect" because of this for it is for the child a reasonable explanation of those features of his environment which the student perceives. It is preferable to label these natural frameworks "alternative hypotheses" (Driver and Easley, 1978).

Since these alternative hypotheses are built on a small area of awareness, the student has much the same available data in interpreting his environment as had his ancestors of hundreds of years ago. As his experience increases, so will his framework of knowledge be modified and expanded. In his studies on the development of thought in children, Piaget describes the small child's conception of clouds as being something alive and conscious (Piaget, 1965). The child's view has its counter-part in the makers of myths and

fantasies in folk-lore and fairy-tales. The older child may entertain theories on motion which are Aristotelian in nature. One such idea, that motion requires a force to sustain it, is logical in a world where frictionless motion is never encountered in everyday life.

"Piaget.....has found that ontogenesis, or individual development, frequently patterns or recapitulates sociogenesis, or collective development."

(Ginsberg and Oppen, 1969)

Newton's laws of motion, although simpler and more scientifically satisfactory in the analysis of motion than the ideas of earlier philosophers are not likely to be developed by an individual without instruction. Even Newton acknowledged his debt to others:

"If I have seen further, it is by standing on the shoulders of giants"

(I. Newton, letter to Robert Hooke quoted in Koyré, 1965)

This is a factor in the perceived difficulty of physics as a study - whilst it explains the physical world, it does so in terms which differ from the student's direct sensory evidence.

An alternative hypothesis being inarticulated and often unrecognised may produce difficulties in the early stages of science education. The teacher often imagines that he is working on a clean slate of the student's mind and is

concerned to present science in a logical sequence of instruction. However, when the teacher and student think in incongruent frameworks and even interpret the same words differently, cognitive conflicts can arise which puzzle and frustrate both student and teacher.

The student can respond in a variety of ways: the more confident student or one who, because of past experience enjoys the scientific environment, may be somewhat flexible and able to modify his framework, providing the adjustment is not in too great a conflict with his alternative hypothesis. This may take some time and never be complete. Other students can be more rigid. If his personal hypothesis about a situation differs too greatly from that which the teacher is presenting, the students may come to inhabit two worlds: an artificial one in the science laboratory and the other in everyday experience. A British Columbian Science Assessment found that thirty per cent of Grade XII students still maintained preconceptions on inherited traits in spite of teaching in genetics which they would have received in school. (Kargbo, 1978).

Pepper has described several "World Hypotheses" of which four, in his view, are "adequate": that held by the formist, the mechanist, the contextualist and the organicist (Quina, 1971). According to Pepper the physicist's view is essentially mechanistic, he pays attention to the shape, weight and solidity of an object and its gravitational attraction as opposed to observing the class to which the

object belongs (as noted by the formist), the conditions of the object and its situation (seen by the contextualist) and the whole history of the object as well as its present condition (noted by the organicist). To some extent depending on the context, we all diversify our perception to suit the situation. A physicist does not usually attend a symphony concert to observe the vibration of the strings or drums or the resonance of a column of air in a wind instrument.

Pepper's view seems too extreme and exclusive. Yet few could dispute his suggestion that the scientist's attempt to study his environment purely objectively can be strange to a young student. In particular, the physicist's mechanistic view of the world is alien to many students, perhaps especially to girls. Either from social or physiological causes, girls seldom seem to interest themselves in mechanistic toys, in space science and so on. For such a student, the conflict in adjusting to a new view in order to comprehend physical concepts may cause him or her to lose confidence and in so doing bring about an inability to adapt.

This is not necessary. A wise teacher, knowing of the probable existence of the student's preconceptions and something of their possible nature, can set up some cognitive dissonance which may help the student to prepare to accept a new conception more in line with that of the teacher.

For example, as many studies have shown, students often believe that all motion is expendable, that a certain amount of energy will cause a body of a given mass to travel a certain distance horizontally. This they have learned from every-day experience. The teacher can bend a plastic curtain rod into a vertical U-shape with sloping sides. A marble is allowed to roll down one side and rolls up the other side almost to the same level on the other side. If this second side is made to lie more at a lower angle to the horizontal and the ball is released again from the same height, it will travel, not the same *distance* but up to the same *height* on the second side. By extrapolation, the student sees that if the second limb were horizontal, the ball could theoretically go on for ever. Although energy is lost in the same way as in horizontal motion, this is not as significant a factor as that the ball always goes to the same height, no matter what the angle. Historical beliefs are a rich source for cognitive dissonance. Many students believe as did Aristotle, that heavy bodies fall faster than light. Two bodies the same size and mass will fall at the same rate but will they fall faster if they are joined together? What happens if two more are joined on?

Aguirre (1980) interviewed elementary school children on tasks involving forces. He suggested that students should be grouped according to their preconceptions of physical situations. Then the teaching strategy for each group can be modified to start from the beliefs held by the group.

On the basis of the few relevant studies in the literature, e.g. Driver (1973), it appears that the conflict between the student's framework and accepted physical theories (or the teacher's framework which may be different from the latter in some details) has many facets:

1. the interpretation of a teacher's words,
2. the predictions the student will make, and
3. what factors the student sees as important.

These will depend on his cognitive framework and affect his understanding (Driver, 1973).

1. The interpretation of the teacher's words depends on the student's acquisition of certain concepts. In the area of force and motion, there are several basic concepts which can cause trouble, especially the abstract concepts such as force, speed, velocity, acceleration, gravity, etc, which are frequently used in everyday life in a loose, inexact and interchangeable manner. Common use of these words is not clearly defined nor is it invariable with time. For example, speed and velocity are not distinguished as different entities in common parlance and are often interchanged with acceleration. Until the student can discriminate clearly between them, he will be unable to formulate any meaningful scientific interrelationship among them (Kendler, 1964).

Piaget (1973) says that the child does not use adult language as we use a foreign language - interpreting ready made concepts point to point. He

constructs a notion to correspond to a word, (p. 40). Until the student has had experience with the use of a word in the context of science, he will not have modified his conception of the term sufficiently to comprehend the teacher's use of the term.

2. The predictions the student makes will depend on the relationships among the concepts, whether false or true, which he perceives. In physics, the scientific law could be

$$\text{Mass} \times \text{Acceleration} = \text{Force}$$

but the student's hypothesis could well be similar to Aristotle's:

$$\text{Velocity} = k \times \text{Force} / \text{Resistance}$$

or to Avempace's hypothesis:

$$\text{Velocity} = \text{Force} - \text{Resistance}$$

(Franklin, 1978)

If, in his early studies, the student's cognitive framework contains such a relationship meaningful to him, then however much he may recite  $F = M \times A$  and solve problems with it, he will experience difficulty in dealing with new situations, e.g., What force keeps a heavenly body in orbit?

3. The factors which the student sees as important can also interfere with his building of the intended logical framework. If in a situation in dynamics, he sees the speed of a car as being more significant than the increase in speed in relation to the force, or in a

problem in statics, he sees the length of a piece of string over a pulley as a significant factor in determining the force exerted by the weight at the end (Aguirre, 1978), he will have obvious difficulties in building an undistorted cognitive structure. In the latter case it is a simple matter for the teacher to point out the insignificance of the string. In the former case the perception of the difference between speed and acceleration may be a complicating factor.

#### B. The Purpose of the Study

The purpose of this study is to investigate the nature of the underlying cognitive structures of the alternative hypotheses which might affect student understanding of the conception of motion as expressed in Newton's laws of motion.

In more detail, the study attempts to investigate the questions:

1. What is the nature of the Grade X physics students' preconceptions of motion in the conceptual areas of:
  - a. inertia
  - b. the effect of forces on the motion of an object?
2. To what extent are these preconceptions held by Grade X physics students in Edmonton Public Schools?
3. Is there any consistency in the type of preconception held by the student about various situations presented to him?



4. Is there any relationship between the type of preconceptions which the student holds and his achievement in physics at the end of instruction as demonstrated by his performance on the criterion test and his school assessed end of term mark in physics?
5. In what way do the alternative hypotheses parallel earlier theories held by Aristotle or Galileo or other philosophers before Newton?
6. Is there evidence that the alternative hypotheses have been modified by the students' exposure to space travel, science fiction, etc.?
7. Is there any sex difference in the type of preconception held, the cognitive stage of the student, his/her achievement in physics or in any interaction of these elements?

#### C. Implications of the Study

A knowledge of the alternate structures which might be possessed by the students in a class is not only important for the teacher but for the curriculum maker as well. If the student's perception of a concept differs from his teacher's, his acquisition of the scientifically approved principles may be affected. It would seem advisable to introduce certain concepts such as force and energy earlier in the curriculum to build up a more concise, useful meaning for the student before he studies dynamics and to direct his attention to those aspects of his environment which are

relevant to understanding physical processes.

Both teacher and curriculum maker can also use these possible alternative hypotheses of the students in considering various approaches to certain topics. This is particularly valuable with the more recent courses in physics such as *Harvard Project Physics* (1970) and *Physics: A Human Endeavour* (Paul, Pierce and Stief, 1973), which stress the historical aspect of Physics. Knowing that respected philosophers held the same views as he has developed for himself, can give a student confidence and encourage him to discover how later scientists used these conceptions to develop theories which gave simpler laws to explain the observed facts.

#### D. Definitions

concept - for the purpose of this study will depend on the isolation of some aspect (or set of aspects) of the stimuli. Examples of such concepts are: mass, force, velocity and acceleration which can be qualitative or quantitative and inertia, causality and reversibility which are purely qualitative.

---

<sup>1</sup> The definition of a concept is extremely difficult. As Kendler (1964) has said, "The concept of the concept is still vague and amorphous."

Some psychologists classify the concept in terms of personal involvement. For example, Jenkins (1966) has suggested three kinds of concept:

1. concepts dependent on shared characteristics (as in this study)
2. concepts defined in terms of a common response or set of responses which the subject makes to disparate physical stimuli,

**conception** - belongs to a particular individual and will generally differ at different stages of development.

**framework of knowledge** - is the total sum of knowledge in the public sense about a system or systems.

**hypothesis** - is a scientific belief or expectation that is held publicly about a system or systems.

**misconception** - is an invalid concept or relationship between concepts acquired by a student during instruction.

**preconception** - is a concept or relationship between concepts acquired by a student before beginning instruction in a subject.

**alternative framework** - will be used to refer to the total knowledge a person has about a system or systems. It determines the perceptual aspects of the system which he

(cont'd)3:

concepts based on systematic relations, e.g., what is a meaningful sentence?

Others classify concepts in terms of their characteristics (Kaplan, 1964):

1. observational terms, e.g., length,
2. indirect observables, e.g., velocity, acceleration,
3. constructs - not observable but defined in terms of observables, e.g., instantaneous velocity,
4. theoretical terms - meaning given by the part a concept plays in a theory.

considers important and is the basis on which he makes his predictions about the system. The term framework does not imply a rigid structure but a flexible and even nebulous construct in some areas.

**alternative hypothesis** - is a preconception or set of preconceptions held by a person before instruction in a subject, e.g., the Aristotelian hypothesis of motion.

**protocol** - is the term used for the transcripts of the recorded student interviews.

**instinctive** - will be used to describe a response prompted by a natural or acquired tendency or aptitude.

**intuitive** - will be used to describe a conception known or learnt without the conscious use of reason.

**sophisticated** - will be used to describe a highly complex or developed conception

**mature** - describes a fully developed, perfected, worked out conception.

**immature** - describes a conception not finished or perfected, incomplete.

**primitive** - will describe a response which is imitative of earliest times, simple or original.

**criterion test** - is the test devised by the investigator on the topics associated with the tasks of this study. It was presented by the teachers in the schools as an important test. The marks recorded in this study were obtained from marking by the investigator.

**end of term marks** - were the marks assigned by the teachers in the schools to the students at the end of the semester's work in Physics 10.

**conservation of motion** - is a psychological construct borrowed from Piaget (Inhelder and Piaget, 1963) which indicates that a student realises that motion does not dissipate except by the action of an external resistance. It is not intended to represent a conserved concept in physics such as momentum which is conserved in a collision or energy.

#### **E. Limitations of the Study**

In considering the outcome of this study, various limiting factors should be considered.

1. The results of the study must be confined to the student population from which the sample was randomly selected, that is, Physics 10 students in Edmonton Public High

Schools.

2. The application of cognitive stages to the students' replies was intended only for comparison purposes between the nature of preconceptions revealed by students on the different tasks. Since only one criterion was used for assessment in each task, these stages do not fully represent those described by Piaget.
3. The interview situation places limitations on the validity of the results:
  - a. The student may be inhibited by certain factors in the environment such as the school atmosphere or by perceiving the study as a form of testing.
  - b. On the other hand, the student may be encouraged to produce ideas which are not part of his personal cognitive framework by overt remarks of the interviewer or by non-verbal signals despite efforts to reduce these. However, while these may be important for a psychologist, the teacher is more interested in the ideas which a student would possess in a similar situation in school.

#### F. Delimitations of the Study

In selecting the students for a feasible study, certain restrictions were unavoidable:

1. The study was confined to Physics 10 students at the beginning of the introductory semester in physics.
2. Only students from Edmonton Public Senior High Schools

were used in the study.

3. The study was confined to investigating preconceptions in the areas of Newton's First and Second Laws. Newton's Third Law of Motion was not included in the main study.

## Chapter II

### REVIEW OF THE LITERATURE

#### A. Elementary School Studies

The study of the development of scientific concepts in children is dominated by the work of Jean Piaget and his colleagues in Geneva. On the basis of clinical interviews with young children ages 4 - 15, Piaget traced levels of development characterised by specific intellectual skills. Briefly, these are: Pre-operational, ages 4 - 6 years, concrete operational, 7 - 10 years and formal operational, 11 - 15 years. In the preoperational stage, explanations of physical situations given by children are often animistic, sometimes magical or mystical. The second stage is characterised by the acquisition of conservation of length, mass, volume; the child is not aware of inconsistencies in his statements or contradictions with other known facts. In the third stage, the child is able to reason with concepts, abstract properties and theories and uses symbols to express ideas. He is critical of his own reasoning (Karplus, 1977).

As an example, one experimental problem presented to Piaget's subjects was a ball launched by a spring device along a horizontal plane. The child whose reasoning powers were pre-operational, explained the motion of the ball as due to a force possessed by the ball. When the force was used up, the ball stopped. The explanation by the child in



this stage answered the question "Why does it move?" It is only in the formal stage that conservation of motion is acquired and there is complete reversal of the explanation to answer the question "Why does it stop?" (Inhelder and Piaget, 1958).

For other physical problems, subjects in the formal stage were able to give correct explanations for the unwinding and winding of a yo-yo in play, a balloon released with air escaping and for problems in inertia.

There is no doubt of the fertility of Piaget's work but he himself acknowledged that his results with children from the better schools of Geneva differ from those with students from other types of school and other social environments (Piaget, 1972). While Piaget found most students had reached the formal stage by 15 years, Renner, Grant and Sutherland (1978) tested 588 secondary school students in Oklahoma for formal and concrete thought and found the percentage of formal thinkers rose from seventeen per cent in Grade 7 to only thirty four per cent in Grade XII. Griffiths (quoted in Driver and Easley, 1978) found "a significant proportion" of 11 - 12 year-old British pupils from "different ethnic groups and home environments" still maintain animistic beliefs about a range of objects or events.

King (1961) found ten per cent of eleven to twelve year-olds attributed life to such objects as sun and fire. He was unable to find evidence of Piaget's stages of development but described a gradual development of reasoning

processes by a more systematic organisation of concepts.

In an analysis of studies on elementary school children, Voelker (1973) concluded that children know more about many science concepts than can be found in instructional materials for their ages and grades. They are often able to deal with functions of concepts without having names for these concepts.

Other studies on elementary school children have indicated that explanations which children give for phenomena do not fall easily into Piagetian categories. Oakes (1947) interviewed over one hundred and fifty children aged from five to eleven years and studied their explanations of natural phenomena. He found that the seventeen types of response which Piaget described in his early work were not adequate for understanding the nature of the responses. He and other psychologists were attempting to analyse the nature of the childrens' responses, not to present an interpretation of the workings of a child's mind as did Piaget.

#### **B. High School Studies**

Many studies have attempted to assign cognitive stages to students with no clearly consistent results. The number of students of the same age classified as being in the stage of formal operations varies between experimenters and for one experimenter varies from one task to another. The results for various experimenters assessing thirteen year old students varies from sixteen per cent to seventy five

per cent of the students being assigned in the stage of formal operations (Hobbs, 1977).

In a study of Grade X chemistry students from high schools in Edmonton, Alberta, Wheeler and Kass (1977) found that as many as fifty per cent of their sample might be non-formal in their thinking. This study might be compared with the present work which deals with a similar sample from the same city.

Research on science concept attainment in high school students is more difficult to find except in the study of misconceptions after or during tuition. Kass and Wheeler (1979) investigated problem areas in chemistry, particularly in students' acquisition of the mole concept. Because of the nature of the subject, problems here seem to be due to students' inability to reason with abstract concepts or to misconceptions acquired during instruction rather than to any preconceptions they might have. This is to be expected since chemical ideas are seldom encountered before school instruction. (Kass, 1977).

In the field of genetics, Kargbo (1978) found that children aged from six to thirteen years already possessed preconceptions on inherited characteristics. The younger children seemed to be more rigid in their ideas and the older students seemed to be more flexible.

Physics education is a much richer source of preconceptions. Leboutet-Barrell (1976) gave 10 questions to 500 high school students before they received instruction. He

found that at about 14 -15 years there was a sudden increase in the students' vocabulary which clarified their explanations but the common use of words rather than the scientific concept was still prevalent. After 6 months instruction he found these preconceptions were still present and that they interfered with the acquisition of scientific concepts. With such large numbers and paper and pencil tests, it was not possible to gain a detailed knowledge of the students' alternate frameworks.

More recent studies of preconceptions have concentrated on identifying the nature and extent of preconceptions before instruction. From a study of the attainment of conservation of volume, Hobbs (1973) suggests that the concept of volume should be taught *at the same time* as the concept of density and not before which is usually the case. Erickson, (1977) identified certain patterns of belief on heat and temperature in twelve year old children. He found certain conceptions were widespread in the sample. For example, heat and sometimes cold was regarded as a type of subtle substance capable of flowing into or out of objects.

In a study of preconceptions about force, Aguirre interviewed students aged from six to fourteen years. He found that many students believed that forces acting at a point disappeared when equilibrium was attained. He also found many students believing that washers were "heavier" nearer the ground. He indicated that students also had difficulty with the composition of forces. In a later study,

Aguirre (1980) used the results of the previous work to set a questionnaire to Grade 8 students. Based on the preconceptions found, Aguirre suggested strategies for teaching force concepts which begin with the students' own ideas.

Investigating childrens' beliefs about free-fall motion, Kuhn (1979) found many students believed that force was necessary to maintain motion. He interviewed students from Grades 6, 8, 10 and 11 and decided that even Grade 6 students were ready to consider these concepts at least qualitatively.

Champagne, Klopfer, Solomon and Cahn (1980) found that not one of their "academically talented" seventh and eighth grade students conceived of motion in Newtonian terms. Champagne et al. found that ten of the twelve students interviewed believed that the force of gravity increased over a one metre distance as an object fell closer to earth. Their students did not differentiate between mass and weight, volume and speed or velocity and acceleration. They also found that their students did not possess even a rudimentary concept of inertia. (Champagne et al., 1980).

Significant gender differences were found by Lynch and Paterson (1980) for the recognition of science concepts such as atom and molecule, proton and electron in students from Grades seven to ten.

## Chapter III

### THE INVESTIGATION

#### A. The Pilot Test

##### The Subjects

The subjects for the pilot study were sixteen Grade IX students, eight girls and eight boys, who intended to take Physics 10 in Grade X. Fourteen students were from a Junior High School close to the university and two from an academically orientated Junior High School.

Since the pilot test took place near the end of the school year, in June, these students would be similar in cognitive ability to the students in the major part of the study, Physics 10 students at the beginning of their course. Participation was voluntary so the sample was composed mostly of students who found physics fairly easy.

##### The Tasks

Nine tasks were devised each of which demonstrated one of Newton's Laws of Motion (see Appendix 1). Five tasks described the first law, two the second and two the third. >

##### Procedure

The allocation of experiments was arbitrary, those seeming to yield the most interesting results were most frequently used.

It was fortuitous that the number of girls and boys given each task is equal. The number of tasks per student varied from four to seven.

Since this was an exploratory exercise, a set of questions was established at the beginning and modified as the study progressed to a more rigid format.

The purpose of the interviews was to determine the pre-conceptions of the students in the tasks set. As the students performed the tasks, the interviews were recorded with the students' previous permission. The tapes were later transcribed.

#### Treatment of Results

The transcripts of the interviews were analysed for the concepts most frequently expressed by the students. A record was kept of the frequency of expression of these concepts and a study made to note those tasks most fruitful in revealing the pattern of thought in the students.

From this study four tasks which appeared to provide the most useful results were selected for the main study. Three of these tasks dealt with Newton's First Law, the balls in the groove, the ball in the cart and the spaceman in orbit; the fourth task, the cart pulled by a weight over a pulley, dealt with the second law of motion.

The transcripts were also studied to attempt to determine how students use scientifically defined terms. By doing so, it was hoped to determine to what extent these concepts

were differentiated by the students and the manner in which they were defined.

### **B. The Main Study**

The period during which the interviews took place was the last week of September and the first two weeks of October, 1979. At this time the students had not begun to study Newton's Laws in Physics 10 although at least six of the subjects had studied inertia in Junior High school and Task 3 was not new to them. Since "inertia" is part of the curriculum for Grade 9 science, it is most probable that many more of these students had been exposed to some teaching of inertia but had forgotten it. This would be the situation in any Physics 10 class in Edmonton. Before the ending of the interviews, some of the classes had begun a study of acceleration as became apparent in Task 4 but most were still covering the mathematics required for the course.

### **The Subjects**

The subjects for this study were forty Physics 10 students from four senior high schools randomly selected from the Edmonton Public School system. It was originally intended to use two randomly selected classes from each of these schools but it became expedient to use three classes from one school, one from another and two from each of the other two schools. These classes were randomly selected from the Physics 10 classes in the schools and five students were



randomly selected from each class.

The distribution of the subjects by age and sex is given in Table 1. The ages are given for September 30.

The normal age range at this time for Grade X would be 14 years 7 months to 15 years 9 months. In some schools, however it is common for students to enter Physics 10 in Grade XI which would account for the large number of students in the 15 years 7 months to 16 years 6 month age group. The older students were in Grade XII and/or had taken longer to complete their schooling. This would be an expected distribution of ages in Physics 10.

Twenty six of the subjects were male, fourteen were female. This proportion of sixty-five per cent males can be compared with the male/female ratio for Physics 10 enrolment in Alberta high schools for previous years. The percentage of males enrolled in Physics 10 in Alberta in 1975, 1976 and 1977 were 67.6%, 66.3% and 65.7% respectively, (Kass, 1979). A proportion of 65% males for 1979 is a reasonable extrapolation.

### **The Interviews**

The interviews varied in length from fourteen to thirty eight minutes. This generally reflected variations in loquacity of the students but there were some unavoidable constraints such as tests in the classroom and delays in appearance of the students because the teacher forgot. These delays were not important since it was possible to cover all

Table 1

Distribution of subjects by age

	Age in years on September 30, 1979				
	14.6- 15.6	15.7- 16.6	16.7- 17.6	17.7- 18.6	18.7- 19.6
Sex					
Girls	6	8	-	-	-
Boys	13	10	1	1	1
Total	19	18	1	1	1

of the tasks in the remaining time.

The interviews at three of the schools (with thirty of the students) took place in an unused laboratory at the school. At the other school, a small Physics office not in use during classes, was made available for the interviews.

The interviews were tape-recorded with the students' consent.

Most students, although initially nervous about being recorded, were cooperative and friendly. There was one exception - a girl who answered as briefly as possible. She had the second highest mark in the school end of term marks but came low in the third quartile for the criterion test mark - the greatest difference in position of any student. This suggests she may be an industrious student during the term who performs poorly under examination conditions. Her conduct during the interview could perhaps be attributed to fear that she might fail.

#### Analysis of Interviews

The transcripts of the tape-recorded interviews were studied and analysed in three ways:

First, on scrutinizing the statements which the students made in answer to each task, it was found that several statements made by different students were expressing the same concept. The statements made for each task were listed and grouped together under the concept which they expressed. A chart was drawn up for each task indicating

the concepts expressed by each student and if there was more than one, the order in which they were expressed. In this way, a conceptual profile for each student was obtained in each task (see appendix 2). From this chart, a frequency table for the concepts suggested by each task was generated.

Secondly, the concepts for each task were reviewed and compared to assess a progression from the most primitive to the most sophisticated explanation or description of the task. From this and the student's conceptual profile, a cognitive stage for each student was assessed. The sophistication of the explanation and the cognitive stage of the student were determined by the degree to which he or she conserved motion.

Thirdly, further study involved comparing these two factors, the concepts expressed and the cognitive stages assessed, with the students' performance on the criterion test, with individual items on the test and with their end of term marks as assessed by the school. The variation of cognitive stage between tasks was also studied.

It was hoped to determine by this method of analysis whether there is any association between the preconceptions of students at the beginning of Physics 10 and their cognitive stages at that time and their achievement at the end of the course and, if there is a relationship to determine its extent.

## The Tasks

### Task 1. Horizontal motion along a groove.

The apparatus consisted of a metal groove supported horizontally by two pieces of wood, (see Figure 1). Attached to a spring at one end, was a "striker" - a square tablet of wood which fitted in, at right angles to the groove. The striker could be pulled back by a nail and released. On the sides of the groove were two marks: To one the striker was retracted each time to ensure that a constant amount of potential energy was given by the spring. On the other mark, the near side of the marble or ball was placed so that the spring was always travelling with the same speed when it hit the ball. Although the striker would lose less energy to the smaller ball, the difference in mass of the balls was so small in comparison with the difference between their masses and that of the striker that almost the same energy was given to each ball. More importantly, the students assumed that the energy was the same in each case.

The student was asked to explain what would happen when the first ball was struck and "Why?". This was often difficult for the student to answer because he could not be sure of what was required. If so, he was immediately asked the next question. The ball, a steel marble, was propelled along the groove. It was so arranged that this ball stopped about half way along the groove.

The student was then encouraged to pass the other two marbles so that he could feel their weights relative to that



Spring

○ Glass Marble ● Small Steel Ball ● Large Steel Ball

Figure 1

Horizontal motion along a groove

of the other ball without his attention being drawn to this factor. One was a glass marble of the same size but smaller mass than the first, the second was a steel ball with a diameter about twice that of the other two and was therefore considerably heavier.

The student was asked whether there would be any difference in the way these two balls behaved and to explain his answer. Each ball was then shot along the groove and the students were asked to explain the result.

#### **Task 2. Inertia of a ball in a cart**

A small open cart with sides and a handle was presented to the student. A small marble was placed in the centre of the cart, (see Figure 2). The student was told that the cart would be sharply pulled along the table and equally suddenly stopped. He was asked to predict what would happen and to give his reasons why.

This task was often used in Junior High School to demonstrate the concept of inertia. Some of the students remembered having seen it performed and some could remember an explanation though not always accurately.

#### **Task 3. Inertia in space.**

While the other three tasks were in random order, this was attempted last so that the student would always have had experience with the inertia in Task 3. It took the student away from the context of the earth into space and tested his

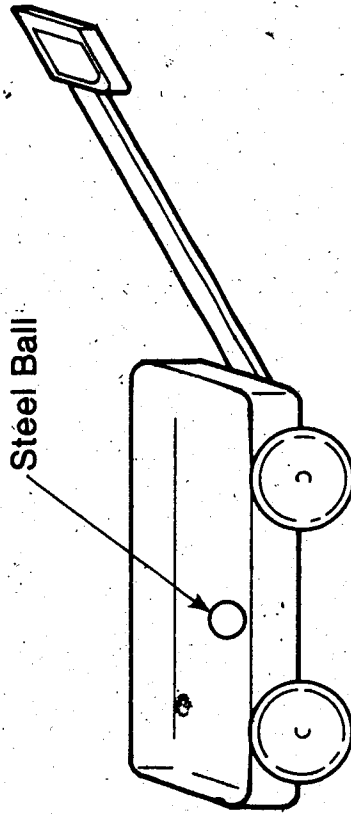


Figure 2

Inertia of a ball in a cart

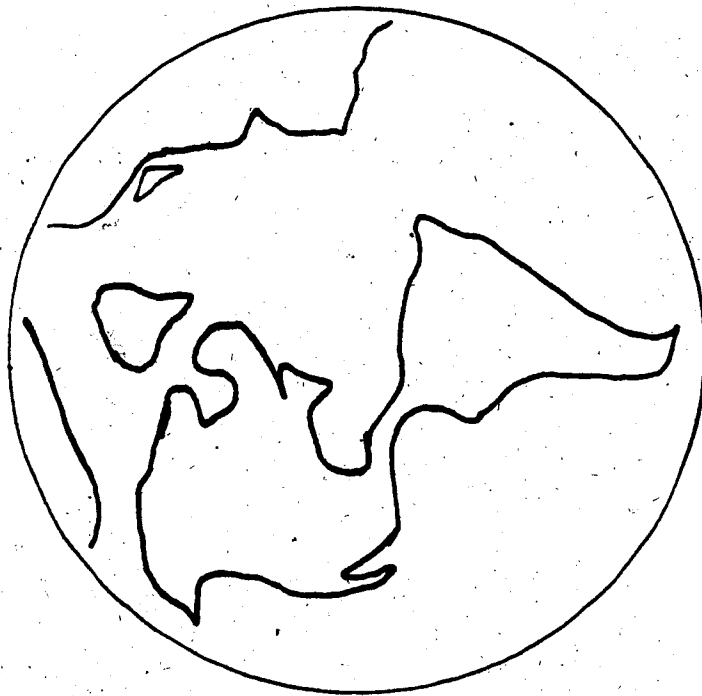


ability to transfer his ideas to space.

A large globe of the earth was shown, a model spaceship and plasticine spaceman, (see Figure 3). The spaceship with the spaceman inside was demonstrated orbiting the earth in a trajectory which took them over the north and south poles. The student was then told: "The spaceman heard a noise outside, put on his spacesuit and went outside to investigate. When the spaceship was here (over the equator) he happened to let go of the spaceship. Where would he be when the spaceship was over the North Pole and why?" It was mentioned that the spaceman was wearing a spacesuit thus indirectly reminding the students, it was hoped, that there is no air and therefore no resistance to movement at the height at which a spaceship is in orbit. When the student had replied, there was often some discussion. Then he was asked what would happen if the spaceman did the same thing in space but this time *pushed* away from the spaceship. Was there any way he could get back?

#### Task 4. Acceleration produced by a constant force.

In this task, a small cart on a table was attached to a hanging weight by a string over a pulley, (see Figure 4). The length of string was so arranged that the weight reached the ground as the cart touched the pulley. There would thus be a constant acceleration when the cart was released from its initial position.



Globe Representing Earth

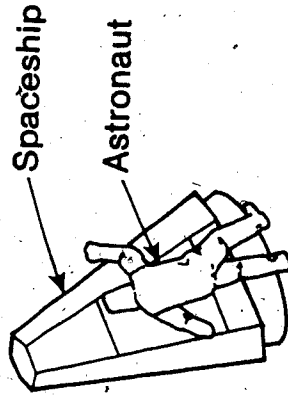


Figure 3

Inertia in space

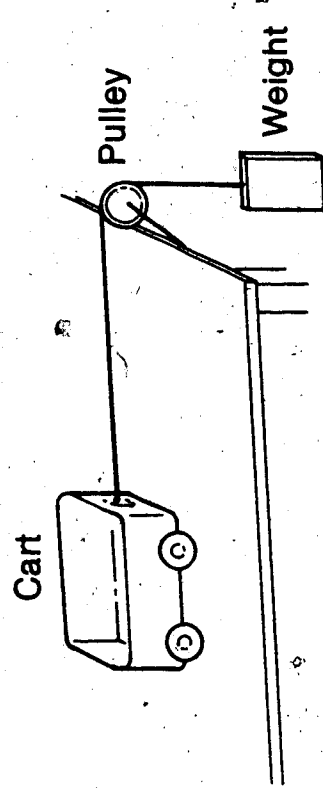


Figure 4

Acceleration produced by a constant force

The student was first asked to predict what would happen when the cart had been pulled back and released. The experiment was performed and the student asked the reason for the type of movement.

Next, the string was made longer and the student asked whether there would be any difference in the movement and why. The weight would reach the ground when the cart was about half way to the pulley and the cart would travel then with a speed slightly decelerated by friction.

#### The Criterion Test

In order to make a reliable comparison of the achievements of the students a test was devised which is named the 'criterion test' (see appendix 3). This test was composed of twelve items, three items dealing with each of the subjects involved in the tasks. For the three items pertaining to each task, one was straight recall, one involved application of formulae or knowledge taught in Physics 10 and the other involved transfer of learned material to a new area.

The criterion test was set in three schools at the end of the semester as an important review which the students believed carried marks. At the fourth school from which were supplied five students, the test was given as the end of section test. The tests were all marked for the purposes of this study by the investigator. One student missed the test and for one other the test paper was mislaid.

**End of Term Marks**

The teachers' end of term marks were collected for thirty eight students - two students had dropped the course. These marks were used to investigate what relationship might exist if any, between a student's achievement in Physics 10 and his conceptions at the beginning of the course.

## Chapter IV

### ANALYSIS OF PRECONCEPTIONS

Analysis of the student interviews will be presented from two perspectives. In the present chapter, after a brief description of each task<sup>2</sup> the scientifically accepted interpretation of the task will be given. Based on this explanation and on a psychological interpretation of the data, a method of analysis of the concepts will be described and explained followed by a frequency table of the occurrence of these concepts. Parts of some interviews will be quoted either to clarify the conceptual basis of the analysis or to demonstrate the students' mode of response.

From this presentation it is hoped to demonstrate the nature and extent of the preconceptions which might be expected in a typical Physics 10 class in Edmonton Public Schools and to identify any sex difference in the type of preconception held if such exists. It is also hoped to discover whether preconceptions held by these students in any way parallel theories held by some philosophers before Newton or if there is any evidence of modification of student thought by exposure to space travel or science fiction. If there is, it is hoped to clarify the nature and extent of this modification.

After this general investigation of each task across the student population, the next chapter will deal with an  
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<sup>2</sup>more complete descriptions are provided in Chapter III

analysis of the protocols of the individual students. By studying the total response to a task it is hoped to gain a more valid description of a student's conceptual framework in that area. It should then be possible to test the consistency of a student's responses across tasks and the relationship, if any between the student's conceptual level on each task and his success in Physics 10 as demonstrated by his end of term marks and his performance in the criterion test. Any sex difference will also be investigated.

#### A. Task 1: Conservation of Horizontal Motion

In this task, the ball was to be projected along a groove by means of a spring and the student asked to predict and explain the resulting motion of the ball. Then two other balls of different masses and/or size were produced and the student was asked to predict their movements and explain his predictions. In each trial, the spring was retracted the same amount and the ball placed with its near edge on the same mark. This ensured that the same amount of energy was given to the balls each time.

A ball of mass 'm' will move along the track with a velocity 'v' which will depend on the amount of energy 'E' given the ball by the spring and which will be determined by the relationship

$$E = \frac{1}{2} m v^2$$

According to Newtonian mechanics, the ball would continue

with this motion were it not for resistance due to the frictional forces. Because its mass is greater, the large steel ball will move most slowly also the gravitational force pulling it closer to the track is larger. Thus the frictional retarding force is greater and is acting on a larger body so the retardation is the same. Since the larger ball is moving more slowly, it comes to a halt sooner, about one quarter of the way down the track. Conversely, the marble having the least mass and the least frictional resistance, will go the fastest and farthest, almost to the end of the track.

A small, contributing retardation which is provided by the air is greater for the large ball than for the other two which, having the same size as each other, would experience the same air resistance.

#### **Motion of a Single Ball**

On studying the interviews it became apparent that there was a limited number of concepts expressed by the students in describing and explaining the motion of the ball.

Inhelder and Piaget (1958) reported the results of a similar task in which younger students between the ages of five and fifteen were asked to predict which of several balls of varying size and weight would travel furthest along a groove. They found from their results that with increasing age of the subjects the responses varied from an attempt to explain why the balls travelled to a concern with why they



stopped. This transition sees an increase in the involvement of resisting forces and as a consequence of this, a development of the conservation of motion.

The first task in this present study so closely resembles that of Inhelder and Piaget described above (although dealing with a more homogeneous age group) that it is convenient to use Inhelder and Piaget's classification of students as a basis for categorisation of the concepts expressed. The concepts can then be designated primitive or more mature by the degree to which they express conservation of motion.

For their subjects, Inhelder and Piaget distinguished concrete operational thinkers, children aged from eight years to thirteen and formal operational aged above thirteen. To define formal operational thinking, they describe eight formal operational schema one of which is composed of "forms of conservation which go beyond direct empirical verification".

Using conservation of motion as the overall basis of classification, the statements of the students can be grouped as expressing the following concepts:

1. The motion of a body requires a continuous force.
2. There is a constant relationship between the force or energy given to the ball and the distance travelled by the ball.
3. A retarding force of gravity acts on the ball.
4. Retarding forces such as friction and/or air resistance

(or pressure) are acting.

5. The ball would continue forever if no frictional forces acted.

The order of these concepts is an increasing importance of slowing down factors. As will be seen later, the use of one does not exclude the use of another sometimes almost simultaneously.

Table 2 presents an analysis of the replies of 92.5 per cent of the students. Of the remaining 7.5 per cent of students, one said he "didn't know" the other two gave no more explanation than "the ball moved forward with the push" and "The ..... (word difficult to hear) pushes it along" neither of which reply gives insight into cognitive processes.

It can be seen from the table that the most common response which was given by half of the students, suggested that the distance travelled depended only on the energy given to the ball. The act of moving uses up the energy or force given to it until it stops thus giving a constant relationship between the energy or force<sup>3</sup> and the distance travelled.

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<sup>3</sup> The terms energy and force often appear to be perceived by the students as interchangeable and do not have the precise meaning they have when used in science. Energy (or force), as used in this context, is some undefined and undifferentiated quantity given by the spring to the ball which causes it to move and which is used up in the course of the movement.

Table 2

Distribution by sex of occurrence of concepts explaining  
motion of single ball

Pattern of response	Per cent responding		
	Boys N=26	Girls N=14	Total N=40
<u>Continuous force is required</u>			
Only response	0	7.1	2.5
Later modified	7.7	0	5.0
Total	7.7	7.1	7.5
<u>Constant relationship between force and distance travelled</u>			
Only response	27.9	57.1	37.5
Plus a retarding force	3.8	7.1	5.0
Plus conservation of motion	7.7	7.1	7.5
Total	38.5	71.4	50.0*
<u>Retarding force of gravity acts</u>			
Only response	3.8	0	2.5
Plus friction	7.7	14.3	10.0
Plus conservation of motion	7.7	0	5.0
Total	19.2	14.3	17.5
<u>Retarding forces of friction and/or air resistance act</u>			
Without conservation of motion <sup>a</sup>	19.2	14.3	17.5
Plus conservation of motion	30.8	14.3	25.0
Total	50.0	28.6	42.5
<u>Conservation of motion</u>			
Total	38.5	14.3	30.0

<sup>a</sup>Only one student mentioned retarding forces only

\* $\chi^2=5.0$ ,  $0.2 < p < .05$  for distribution by sex

Some comments of the students which seemed to imply this relationship are:

- a. *It stops because it runs out of push.*
- b. *The force wasn't enough to push it.*
- c. *It will roll as far as the amount of power put into it.*
- d. *It needs energy to go a certain distance.*
- e. *It uses energy and stops.*
- f. *It loses momentum.*

There is a significant difference between the sexes in the use of this idea, girls being much more likely to suggest it than boys - Chi square = 5.0,  $p < 0.05$ .

Altogether five of the twenty students who responded with this concept later modified their statements by referring to a resisting force and three of these students eventually commented that were it not for friction, the ball would go forever. Barb provided an example of such a change

*B. It would keep rolling forward until it lost the momentum or else it would roll to the end whichever came first.*

*I. How would it lose the momentum?*

*B. The force behind it wouldn't be.... the further away it gets, the more force behind it it loses and so it gradually stops because there's air pressure all around, besides its resistance to the ball kind of slows it down.*

Barb modified her original idea that the ball loses momentum

as it goes along to an explanation that this loss was due to a resistance - concept 4. Piaget might describe this as "assimilation" in which the organism, Barb, modifies her perception of the motion to her cognitive framework of motion which itself undergoes accommodation (Piaget, 1930).

Three students seemed to possess the more primitive idea - that the ball needs a constant force to keep moving.

Their comments were as follows:

- a. *It slows down because there's nothing to keep it going.*
- b. *It slows down because there's nothing hitting it all the time.*
- c. *It slows down because there's no force pushing it.*

Again, one of these students later mentioned resistance as a factor in the motion.

Of the students in this study, half spoke of a resistance, describing it as one or more of the agents of gravity, friction or air resistance. The use of weight or gravity was very personal. Some of these twenty students explicitly stated that the weight or gravity caused friction. David almost seemed to be talking about friction when he said:

- d. *...as the ball's rolling down it gets slower and slower because the gravity's pulling down harder against the steel, it tends to slow down.*

On the other hand, Brian, one of the youngest students who achieved average marks clearly separated the two:

- B. I'm not sure how far it'll go but it'll slow down.
- I. Why?
- B. Because of the gravity and there's nothing making it go forward. The only power it's getting is when that thing shoots it forward and it'll just slow down because the gravity's making it slow down.
- I. The gravity's making it slow down?
- B. And friction on this.
- I. How does gravity make it slow down?
- B. Well, it's pulling it harder to the ground and if it's fast to the ground, you can't act on it as easy and then when the gravity starts it pulls it down and it'll slow down until it stops.
- I. So there's gravity and friction acting on it?
- B. Yes.
- I. If you got rid of all the friction - supposing you could, what difference would that make?
- B. It would go for a longer distance but it would still stop because of the gravity.
- I. So the gravity slows it down?
- B. Yes the friction just slows it down a bit and if you got rid of it all then it would go faster, well it would go longer.

Brian was clearly separating gravity and friction and was

one of those students who believes that a vertical force can oppose a horizontal motion.

Thirty per cent of the students expressed the concept of conservation of motion but only half (6) of these mentioned it as a first response. The other six introduced the concept later. For example Wendy, an above average student in both end of term marks and on the criterion test, expressed several conceptions about motion when asked to predict and explain the motion of the first ball.

*W. The ball will be pushed forward and it'll continue in a forward motion along the strip because the force that you used to pull back is being used in the opposite way to push the ball forward.*

*I. What will happen to it along there?*

*W. It'll slow down - gravity or because the amount of force has been expelled it's been used and it slows down and then plus the gravity and the pressure.*

*I. How does gravity work against it?*

*W. I don't know if the gravity would - I know pressure probably would, the air pressure because it's going against the air pressure and it's having to push its way through so it's slowly losing the force that was given the ball to move.*

I. If there wasn't air pressure would it go on moving?

W. *Theoretically without gravity because once it goes off the end it should fall because of gravity.*

I. So if there was no air pressure and this was infinitely long would it continue moving?

W. *It should, yes. There's nothing else stopping it.*

I. Would it go on forever?

W. *Well if this was infinitely long, yes.*

One might wonder whether Wendy was an instinctive conserver of motion since the question of conservation was not spontaneous. This doubt is reinforced by her reply to the spaceship question:

W. *He's going to follow in the path for a little ways and then the gravity will overcome him and he's going to fall to earth.*

I. Why will he follow in the path?

W. *Because he's going to let go and that's the motion that he's been in the rocket and he's moving at the same speed as the rocket and when he lets go he'll continue but he'll start to slow and fall to earth.*

I. Why will he slow down?

W. *Because he's going to descend.*

Again, gravity was used as a slowing-down agent.



Although the other students had no problem imagining the unidirectional movement of the ball along the track, Deborah (20A), persisted in holding an incorrect expectation for the motion of the ball despite evidence to the contrary. This was her response when asked what would happen to the ball:

D. *The ball will go about to the centre and then it will go back because of the force behind the spring.*

I. Why do you think it will go back?

D. *Just because of the gravitational pull? - (pull? - tape difficult to hear)*

I. Is it on a slope?

D. *No.*

I. Well, what will make it go backwards?

D. *Just the force of the spring driving it.*

I. That will make it go one way and then it will go back. Why do you think it will go back?

D. *I don't know, I just think it will.*

The ball was projected along the groove.

I. Why did it do that?

D. *Because that was all the force you had in the spring. That was as far as it could go.*

I. Why does it need a force to go along there?

D. *It just couldn't move itself, you have to do something to push it.*

I. Why can't it go further than that?

*D. Because that's all the force there was in the spring.*

After the interview, Deborah voluntarily returned to the question:

*D. Wouldn't they go back because you pushed them from the spring forward? Wouldn't they return back because there's no push left in them?*

*I. Why do you think they would go backwards?*

*D. It's just the way it looks they would go.*

When asked whether she had played bagatelle<sup>4</sup>, Deborah agreed but did not seem too sure. Perhaps indeed she had played it but had never perceived the slope on the board. It suggests one possible reason why more boys than girls take physics and seem to find it more appealing - they are more likely to have played a variety of games where kinematics are important and perhaps have thus acquired an intuitive understanding of the motion of objects under varying conditions.

It was found in this task that a large number of responses can be obtained from the students but on analysis only a few concepts, ranging from fairly elementary to mature are found to be represented. Gravity, as well as being confused with energy, weight and momentum, has a very personal and often undefined meaning for the student using

<sup>4</sup> Bagatelle is a table game in which a marble is projected along the side of a gently sloping board. It then falls back under the effect of gravity over the surface of the board and can score points by being stopped in one of several traps.

it. Although the task seems to be very simple, merely the explanation for the movement of a single ball, it is possible for a student to be able to give a false prediction for the movement and to persist in this idea in spite of visual evidence of the contrary.

#### **The Motion of Balls of Different Size and Weight**

When two other balls were introduced to the task, the students' attention became centred on the contribution of weight or mass to the distance the ball goes. This affected the distribution of replies but not the type of concepts used in the two parts of the task so the analysis was performed using the same criterion, that is, the degree to which the students conserved motion. The concepts used for classification were:

1. There is a fixed relationship between the force or energy given to the ball, the mass of the ball and the distance it goes.
2. The distance depends on the inertia of the ball.
3. Gravity or weight is a retarding agent.
4. The distance gone depends on the resistance to the ball.
5. Conservation of motion is explicitly stated.
6. Speed is a determining factor.

Table 3 gives the distribution of these concepts. Also given in the table is the frequency with which each concept was accompanied by some indication of the importance of friction or of conservation of motion.

Table 3

Distribution by sex of occurrence of concepts explaining  
motion of balls of different size and weight

	<u>Per cent responding</u>		
	Boys N=26	Girls N=14	Total N=40
<u>Fixed relationship between force/energy, distance and mass</u>			
Without friction	19.2	57.1	32.5
Followed by friction	15.4	21.4	17.5
Total	34.6	78.6	50.0*
<u>Relationship between inertia and distance</u>			
Without friction	34.6	42.9	37.5
With friction	19.2	17.1	15.0
Total	53.8	50.0	52.5
<u>Gravity/weight as a retarding agent</u>			
Without friction	15.4	21.4	17.5
With friction	7.7	0	5.0
Total	23.1	21.4	22.5
<u>Resistance slows down</u>			
Without conservation of motion	38.5	14.3	30.0
With conservation of motion	7.7	7.1	7.5
Total	46.2	21.4	37.5
<u>Conservation of motion</u>			
Explicitly stated	7.7	7.1	7.5
<u>Speed is the determining factor</u>			
With conservation of motion	3.8	0	2.5

\* $\chi^2 = 7.0$  .01 > p > .001 for distribution by sex

The statements relating to the larger ball are assumed to indicate the same concept when the opposite observation is made for a lighter ball.

The most frequent reply was concept 2, the variation in inertia due to mass/weight. Over half of the students replied in this manner although one third of these later modified their replies with a more sophisticated statement. Phrases which suggested this idea were:

*The spring has more energy when it hits the little ball*

*The spring doesn't have as much effect on the larger ball*

*It's harder to push a heavy object so it doesn't go as far/doesn't go as fast.*

The first concept, a fixed relationship between force or energy and distance and mass was almost as popular. Half of the students replied in this manner although again a third of these later modified it with a more sophisticated statement. Typical descriptions of the fixed nature of the relationship are:

*A heavy object needs more push (force, energy or power) to move a certain distance.*

Students were more likely to modify this concept by referring to friction when comparing the movement of three balls than when describing one.

As when describing the motion of one ball, there was a significant difference in the use of this concept between the sexes. Almost seventy nine per cent (11) of the girls compared with almost thirty five per cent (9) of the boys mentioned the idea. Chi square for this distribution is 7.0,  $.01 < p < .001$ . Since this seems to be a persistent sex difference, one must conclude that girls entering Physics 10 have much less sophisticated ideas about motion than do boys. There is a corresponding tendency for more boys than girls to give sophisticated replies, but the difference is not significant. Nearly all (85%) of the students mentioned either concept 1 or 2. That is, they first said either "It takes more energy to move a larger ball" or "It is harder to push the larger ball" The other fifteen per cent only mentioned some retarding factor being important in the distance the ball went.

Similar to the situation when describing the factors affecting the motion of a single ball, when almost one fifth responded in this manner, one quarter of the students used the term "gravity" or "weight" associated with dissipation of energy to explain the difference in movement of the three balls. Of the eleven students who offered such an explanation involving gravity, two identified gravity with a force downwards which increased resistance:

*Well, that has more weight so there'd be more friction.*

Of the other nine, eight appeared to believe that the pull of the weight or gravity downwards slowed down the motion. For example, Jane when asked what difference gravitational pull would make replied:

*Well it holds it back more, holds it down to the ground more so that it can't move as easily.*

In this case, Jane demonstrated that she was not confused with the direction in which gravity was acting but saw no conflict in describing a vertical force as a horizontal retardation. Claren who, from the difficulty ~~she~~ had with English, appeared to have arrived fairly recently from Asia, recognised the problem. She first suggested that gravity made the heavy ball need more "strength" to go the same distance as the small steel ball but when asked what difference gravity made she said:

*C. I don't think it does.*

*I. Why?*

*C. It doesn't - (pause of 10 seconds) - maybe it does but not a great deal. It's like people walking. When the gravity pulls you down so if the ball has the gravity pull - I don't think it applies because the ball is going all the ways. It's just travelling there it's not travelling up and down.*

Doug was a student who appeared to have more uncommon ideas. When asked to explain the motion of one ball, he suggested gravity without mentioning direction. When asked whether using the other balls would make any difference, he said:

D. Sure it will..weight. The amount of weight on that spot compared with amount of pressure you can put on to it will vary. The lighter the object, the easier it is to push it; the heavier it is the harder it is to push it. You try lifting a box that's light, it's quite easy but a heavy one, it's a lot harder.

I. So what difference will it make.

D. Sure, the heavier one won't go as far as the smaller one.

After establishing the order of the distance the three balls would go, Doug appeared to clinch the argument by saying:

D. Because of weight, also because of size too. The smaller the object is, it's a lot easier to .. I mean size does have its advantage to an extent.

I. Why?

D. It's a lot easier to move something small. A fast ball is lighter than a soft ball and I think you can throw it further because it's easier to grip and it's small but a soft ball is bigger and it's heavier and you've got to use a lot more strength.



In this context, Doug appears to be thinking in a similar manner to Piaget's young students. Piaget (1974) distinguishes weight quantity and weight action in situations of equilibrium. When young children (less than ten years old) first learn to discriminate between the two, "from the point of view of weight action...when it comes to directions followed by the weight considered as force, we observe a curious and rather systematic gap. The weight does not always go down vertically and in some cases does not even have a tendency to go down" (p.91). Although Piaget's students were dealing with static forces (ladders in equilibrium, for example), the conception appears to be similar.

Almost one third (13) of the students mentioned friction or air resistance as a retarding force which varied with the mass. The type of comment made was:

*Air resistance is greater on the larger ball*

*Friction is greater with a heavy object*

There was a greater tendency for boys to mention resistance. Forty six per cent of the boys did so compared with twenty one per cent of the girls.

In this task, the relative motion of the balls was perceived as being more important than the mechanics of the motion of an individual ball, so only three students found any need to mention the conservation of motion compared with twelve when discussing the movement of one ball:

*If there was no friction at all, then they would just keep going.*

Concepts 1 through 5 can be seen ~~as a~~ progression from a rudimentary idea of a fixed association of mass and distance to a more sophisticated awareness of the inertia of a moving object. Statement 6 does not fit in this continuum. The student is paying attention to the speed of the object. *The heavier ball stops sooner because it is going slower.*

"Sooner", in this case, probably means "at an earlier point along the track" rather than "earlier in time". This assumes, probably unconsciously, that the effect of the retarding forces on the three balls is the same, that is, that the deceleration is the same. This is roughly true. Because of the slow speeds, kinetic friction is nearly proportional to the weight and therefore to the mass of the ball. So the retarding force due to friction on the surface of the tracks will be greater on the heavier ball but since this force is acting on a correspondingly greater mass, the net effect will be the same. Thus, the large ball, already slower, will be brought to a stop sooner.

It is doubtful whether Tim, the only student offering this explanation, performed any such involved reasoning. His attention appeared to be concentrated on the different speeds of the balls rather than their different sizes. Once the balls are in motion, and the different speeds established, the masses are irrelevant. Perhaps, if the

students had been asked first which would go *faster* then which would go further, the difference in speeds would have been used more often to explain the difference in distance. It does however, serve to illustrate that within a class, students will select different factors as significant in the same problem.

The wrong predictions which five students made often illustrated some interesting preconceptions; of the three who thought the lightest ball would go least far, Gordon said:

*Because it has the smallest surface area so therefore - if you push it the same, it'll rotate more than that one will or it would.....in that distance it would go round more times and therefore more friction so it would therefore stop earlier*

This is a mathematical problem rather than physical (as in physics) assuming that Gordon believed

$$\text{total resistance} = \text{force} \times \text{distance}$$

and confused distance with the number of times the marble rotated. Tim also, before his explanation which dealt with the relative speeds of the balls, had predicted the marble would slow down earlier:

*Well, it's lighter and the pressure - the weight and everything pushing against it will slow it down faster.*

He did not realise here that although the effect of the frictional force on a smaller ball would be greater, the

force itself was smaller than that on the heavier ball. When he saw the lighter marble go farther, he maintained the same "set" toward the problem, that is, he was concerned with the speed of the slowing-down process and so he proposed the original response, namely that the effect of the retarding force is the same on both balls but the larger ball, moving slower will slow down earlier.

The replies of the two students who said the three balls would go the same distance were totally different.

Geoff said:

G. *There shouldn't be (any difference) even though there's a weight difference. It should travel the same distance (as the first steel ball)*

I. *Why?*

G. *Well, I can't even explain it.*

Carman's reply was more sophisticated:

*It (the large ball) would go very slow but it will probably go as far because it has greater mass and more momentum<sup>5</sup>*

Carman seemed to assume that the retarding force was the same on both balls so the one with the greater momentum, the large one, would go further. Carman was one of the top

<sup>5</sup> In fact, this relationship between mass and momentum, is true if, as is assumed, energy is the same for both balls,  $1/2m_1v_1^2 = 1/2m_2v_2^2$ , that is,  $m_1v_1 \times v_1 = m_2v_2 \times v_2$ , or momentum is inversely proportional to velocity. But rate of change of momentum is correspondingly greater for the larger ball (frictional force is greater) therefore the large and small balls will stop in the same time during which the faster ball, the small one, travelling faster will go further.

students in end of term marks and the criterion test.

In the first part of this task, the students' descriptions of the movement of the single ball always moved from an elementary to a more sophisticated concept. In comparing the motion of the three balls, this was not true. Geoff's response was an example of this. He first predicted that all three balls would go the same distance but after seeing the glass marble travel much further than the small steel ball, he said:

- G. *That was lighter so the gravitational pull is not as strong, I guess.*
- I. *What about this one? (The large steel ball)*
- G. *It shouldn't go as far.*
- I. *Why not?*
- G. *Because it's heavier. It's bigger.*
- I. *What difference does that make?*
- G. *The mass, I guess, but that doesn't make sense because when you drop two objects the same shape but different weights, they hit the ground the same time.*
- I. *But we're not dropping them, we are pushing them along here. There's a difference.*
- G. *Maybe they catch more air because they're bigger.*
- I. *Does the air slow them down?*
- G. *Either that or it's heavier.*

The glass marble and the large steel ball were in turn

projected along the track.

G. *I figure it's the weight now.*

I. Why?

G. *Because that's the same force except it needs more strength to push a heavier object and that being heavier it's the same strength but it's like lifting weight, you have the same strength but you can't lift heavier things because you're not stronger, I guess. So it needs more energy to push a heavier object.*

In this interview, Geoff first mentioned the heaviness of the large ball which might indicate concept 3. Then he mentioned air resistance, (concept 4), and finally decided on the concept of inertia (concept 2). His replies had a different character in the first part of this task, namely:

G. *It wouldn't have enough momentum to go all the way.*

I. Why not?

G. *I wouldn't know, just the gravity, I guess.*

I. What does the gravity do?

G. *It pulls it down, it slows it down.*

I. Gravity pulling it down slows it down?

G. *If it was in space, I guess it would just keep going because there was not too much gravity.*

The above excerpt illustrates a tendency common to many students to be reluctant to consider that there might be more than one factor contributing to the retardation. It

also demonstrates that the conspicuous aspects of a situation not only differ from person to person but vary for each individual depending on the circumstances. There is no guarantee of transfer of conservation of momentum from one situation to another in space. If teachers provide examples and problems in as wide a variety of situations as possible, transfer might be encouraged. Experience with the concept of conservation of motion in this way, having to think instead of applying formulae blindly, might encourage acquisition of the concept.

#### Similarity of Response between Tasks 1A and 1B

Some of the conceptions expressed in describing the motion of one ball and comparing that of three balls are very similar and the correlation of their expression by individual students on the two tasks can be compared using the chi-square test. The use of the conceptions that the distance the ball goes is related to the amount of energy given to a single ball and that the distance is related to the energy and the size of the ball when comparing the three balls seem to be insignificantly related. Chi-square = 1.30.  $p \gg 0.20$ . The use of an idea of frictional force in the two parts of the task is more highly related. Chi-square = 6.41. The probability of this happening by chance is less than 0.02 and greater than 0.01. The use of the term gravity as a slowing down quantity (but not when used as related to a frictional force) in the two parts of the task gives a

chi-square of 4.50 using Yates correction for small expected frequencies. In this case,  $0.05 > p > 0.02$ .

### Summary

The students' mental images range from elementary Aristotelian ideas where continued horizontal motion requires a constant force to the more sophisticated Newtonian concept of conservation of motion. These different ideas are not mutually exclusive, students can express both and many did. Although most students, if they mentioned several conceptions, moved from elementary to more mature, this was not always the case.

To some extent, the task determined the nature of the reply. Approximately one in three students actually mentioned conservation of motion when describing the motion of one ball but less than ten per cent appeared to conserve motion when comparing the motion of three balls.

In psychological tests such as word association primacy of response is assumed to be of importance in indicating intuitive ideas. On this basis, conservation of motion rarely appears to be intuitive in this sample. When presented by students, conservation of motion was usually preceded by a more primitive response.

Such terms as energy, force, pull of gravity are usually used in a colloquial sense. The first two are often used interchangeably while each of the three may be used as a quantity related to mass. When gravity was used in this manner, its possession tended to slow down the movement of a



body. Many of the students' problems in interpretation seemed to stem from the lack of differentiation of these terms as well as ill-definition.

The interpretation of the term pull of gravity is very personal. Of the fourteen students who mentioned the pull of gravity as an agent of retardation, three said the greater weight or pull increased friction and nine implied that the force of gravity downwards would slow down the horizontal motion.

There is only a slight tendency for the same students to use the idea of a fixed relationship between the energy given and the distance the ball goes on the two parts of the task. Students using the concept of frictional forces slowing down the movement of one ball are more likely to use the same concept in explaining the difference in movement of three balls. The probability such a distribution would happen by chance is less than 0.02. Students are significantly more likely ( $0.05 > p > 0.02$ ) to use gravity or weight as a slowing-down-factor apparently not related to friction in the second part of the task if they used it in the first part in that manner.

Girls are twice as likely as boys to suggest that the distance a ball travels depends only on its size and the force given. The difference is significant though only slightly ( $p < 0.05$ ). There is a tendency but not a significant one for boys to give more mature responses including the importance of friction and conservation of motion.

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**B. Task 2: Inertia of a Ball in a Cart**

In this task, a ball was placed in the middle of a cart and the student asked to predict and explain the motion of the ball if the cart is suddenly pulled and after a short run is suddenly stopped. Then the demonstration was performed and the student asked for an explanation again.

There are three constituents of the motion of the ball and cart: The first is the initial movement of the cart forward while the ball remains still. Because of the relative motion of the ball to the cart, it appears to most people that the ball moves to the back of the cart. The second element occurs when the back of the cart hits the ball, setting the ball in motion with it and the third factor is the continued movement of the ball forward when the cart stops.

**Predictions**

The topic of inertia is in the Alberta Junior High school curriculum for Grade 9 and Task 2 would be a likely demonstration for illustration. It was therefore not surprising that three-quarters of the students knew what to expect. Whether they described the anticipated motion as a movement of the ball backwards then forwards, or as stationary then forwards, they were predicting correctly depending on whether they were describing the relative movement of the ball to the cart or its absolute motion.

### Analysis of Concepts

In analysing the replies to this task, it is convenient to classify four groups indicating increasing understanding of inertia.

1. The most elementary response is one in which the agency of some force was proposed to push the ball backwards or to hold it stationary or push it forward when the cart stopped.
2. A more mature notion was one where an agent of weight or gravity was suggested which seems to have some kinship to inertia.
3. An even more sophisticated response recognised more fully the idea of inertia acknowledging that the ball does not "wish" to change its state of rest or of motion.
4. The fourth concept was that of inertia.

The frequency with which these responses occurred is given in Table 4. The total of responses is considerably more than one hundred per cent because many students gave replies which fell into more than one category or they gave a different type of response for the second part than for the first.

The most frequent response was that given by forty per cent of the students who explained the relative movement of

Table 4

Distribution by sex of occurrence of concepts explaining  
motion of ball in cart

	<u>Per cent responding</u>		
	Boys	Girls	Total
Possession of relative motion	N=26	N=14	N=40
<u>Agent of a force</u>			
Without relative motion	19.2	21.4	20.0
With partial relative motion	7.7	21.4	12.5
With relative motion	7.7	7.1	7.5
Total	34.6	50.0	40.0
<u>Weight or gravity as factor</u>			
Without relative motion	0	7.1	2.5
With partial relative motion	0	7.1	2.5
With relative motion	11.5	0	7.5
Total	11.5	14.3	12.5
<u>Anthropomorphic explanations</u>			
With partial relative motion <sup>a</sup>	3.8	21.4	10.0
With relative motion	23.1	0	15.0
Total	26.9	21.4	25.0
<u>Inertial explanations</u>			
With partial relative motion	7.7	21.4	12.5
With relative motion	50.0	21.4	40.0
Total	57.7	42.8	52.5

<sup>a</sup> All students giving an anthropomorphic and inertial explanation had some idea of relative motion.

the ball and cart by a force or a cessation of force. Five of these sixteen students proposed a force pushing back at the start and three more described this force as an "equal and opposite reaction". Three students decided that the ball rolled forward at the end because of the force backwards ceasing. For example, Chris said:

I. Why did it go forward when I stopped the cart?

C. *Well, when it's back and the force stops, it's way back here and when it stops it naturally just goes forward.*

This idea is contrary to Newton's second law of motion which states that a change in motion can only be caused by an unbalanced force. Here, it is the cessation of force, that is, nothing causing motion. The other five students decided the forward motion at the end was due to a force forward or a change of force.

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 \* It is not difficult to understand the reasons for this type of explanation. A force acting on a body can only be perceived by the results of its action. When students do not notice the ball's movement relative to an external framework, they can only explain its movement in the cart as the result of the action of a force or forces. Piaget, (Inhelder and Piaget, 1958) names relativity of motion as one of the eight formal operational schema (pp. 307 - 329). In discussing the problems associated with this task of the ball in the cart, Piaget (1974) says: "It takes a long time to understand the inertial processes and one can easily see why. Admitting that a marble moves back in relation to a support in motion and stays in place in relation to external references is both to resist the suggestions of trans-missions and to coordinate two systems of reference. On the other hand, the conservation of a rectilinear and uniform movement especially when it manifests itself after the support stops... is not a conservation like any other since it deals with the movement as a state and not with static properties. (p. 85)

Two students postulated a force of the wind pushing the ball back when the cart started. The corollary of this to these students was that when the wind stopped, the ball went to the front. For example, when asked to explain the movement of the ball, Anin said:

A. Well, the force going, the wind came in pushed the ball to the back here and when you stopped it went right to the front.

I. Why? You said it was the wind?

A. Yes, pushed the ball this way, when you stopped there was no more wind it went to the front.

Generally the force itself was undefined but for one student, Doug, it was turbulence. His unedited comments were:

D. In a solid, the molecules don't move practically at all but they are vibrating. In liquids they just rotate in currents - you call them convection currents or something like that. When you've got air around an object, the only reason it's going to stay there if there's no dent there (reference to the small dent in the centre of the bottom of the cart, part of its construction which perturbed only one or two students) is because the gravitational force is being pushed towards it and reflected. All the molecules are bouncing off it as fast as they can go and that's the only reason it's staying there is

because of all the molecules racing towards it and reflecting off and bouncing it. If there's an offset of that, meaning if it's starting to go that way there is going to be a...new current coming in. I mean if you pull in the wall, the air flow is going like this and over and starting turbulence, it's a bit difficult to explain, and forces it back.

Doug's interview was the longest; he was very willing to talk. He barely passed Physics 10 with 40% at the end of the course yet on the criterion test he attained the median score. The idea here of the air flowing over the object and causing motion is similar to Aristotle's theory of violent motion. Once an unnatural motion has been initiated, it is sustained by air rushing to fill the supposed vacuum left by the moving body, the turbulence causing the power to keep the body moving (Randall, 1962). Piaget (1930) also describes a young student explaining the movement of projectiles. The child says that the ball displaces the air of the room which, blowing behind the projectile, pushes it along. In an airless room, the ball would not move and could not of itself produce any air (p. 22). Another student, Wayne, thought that the atmosphere held the ball in position when the cart was first pulled. After explaining adequately the movement of the ball when the cart stopped, he was asked what happened when the cart was first pulled:

W. It's hard to explain. I'd say it's just atmospheric pressure that would hold it there.

As in Task 1, weight or gravity has a connotation of inertia for David:

D. The marble will roll back this way until it hits the back here and keeps going.

I. Why?

D. Gravitational pull pulls the marble down, not across so the marble tends to stay in one place.

The student was one of three students who used weight or gravity in this context in Task 1 as well as Task 3. Anin even attempted to explain how gravity could continue the motion:

A. Gravity pull, once the speed stops, pulls down on it and pulls forwards down.

Geoff was not quite sure exactly how to explain inertia and tried several factors:

G. Like when you're running and suddenly stop, you fall forward. The weight, the momentum and the gravity if you're moving and stop suddenly you'll go forward.

Altogether seven students used gravity or weight to explain the inertia of the ball when stationary or when it was moving. Also Barb, who had one of the highest end of term marks and scored seventy four per cent on the criterion test



compared the ball in the cart with a person in which stops suddenly and said:

B. *Because the car is stopping, there's no force stopping you - you have to stop (when you hit the front?) Well, if the car isn't there, if there's nothing in fact, you keep on going because there's no force stopping what you had. The force is still behind you so it's still pushing you forward.*

I. *So that's why you go forward - because there's a force behind you?.*

B. *OK. When you stop, you go forward. Well, I suppose so that would be the only thing to push you forward because the force in the car is stopped and stopped that force but you'll still be going forward but the car's restricting you from going way out.*

It seems as if Barb has an intuitive feeling for force in this circumstance but explains it in terms of force. In the first task, Barb seemed to think that the object would go a certain distance corresponding to the energy given to it.

Not only were the terms weight, gravity and momentum used to explain the concept of inertia, the ball was also described as "wanting" to stay still or to move:

1. *It wants to stay in one place.*
2. *It's a free object and hasn't been pulled.*
3. *It wanted to stay still.*

and the inertia of the ball when the cart was stopped:

1. *It doesn't know the cart will stop.*
2. *It wants to go.*
3. *It hasn't been stopped.*
4. *It will try to keep going.*

Two students' responses were: "It's not the thing to do" and "It just happens that way".

#### Perception of Relative Motion

It seemed that it was marginally easier for students to explain the inertia of the moving ball when the cart stopped than when the cart was first pulled. Twenty one students seemed to understand the inertia of the moving ball compared with seventeen who could see the inertia of the stationary ball when the cart was first pulled. This might be due to complications in perceiving the relative motions of the ball and cart when the ball appears to move backwards in the cart when the cart is first pulled. Some of the difficulties which the students experienced in this respect of relative motion are illustrated by the following excerpts from interviews with Marsha (M), Shawn (S), Anne (A), Tamara (T), and Eric (E):

M. *Because you're moving this, not that, the ball so it's going to move so when you move that, you're not moving that so it'll go back because that's moving.*

S. *When you're in a car, you're throwing up a ball, the car's going to change its space and that*

tends to move the ball back in a different position and it's the same here maybe; it was changing space - the cart was no longer here it was there and the ball moved with it.

- A. When you start it, it moved back because it has been sitting in one place and it would continue sitting except it can't it goes backwards, I don't understand it.
- T. It stayed in its own place for a while then went back.
- E. It stayed a bit then rolled back and hit the wall.

The above students are beginning to perceive the motion of the ball relative to an external framework but they are not yet independent of the effect of the immediate surroundings of the ball, that is, the cart.

#### Summary

Compared with Task 1, when considering the motion of one ball, where almost one third conserved motion, more than half of the students perceived the inertia of the ball when the cart was stopped and the ball continued moving; that is, they conserved motion. This difference may be due to the fact that many students may have seen this experiment demonstrated in junior high school. If so, it indicates that transfer of conservation of motion cannot be taken for granted.

The inertia of the stationary ball was slightly more difficult for the students to perceive than that of the moving ball. This may be due to the complicating factor of the perception of the relative velocities of the ball and cart when the cart was first pulled.

The concept of weight or gravity as a factor similar to inertia is possessed by five (12.5%) of the students compared with, in Task 1, seven (17.5%) when describing the motion of one ball and ten (25%) in comparing the motion of three balls. Three of these students used the term in the same manner in both tasks. It may be surmised that again previous experience in Junior High School played a part in these differences, some students having learned a scientifically correct explanation for the motion of the ball in the cart.

Three students thought the air pushed the ball to the back of the cart when the cart was first pulled - a primitive explanation. These students were below average in performance on end of term marks and on the criterion test. Five students attributed the movement of the ball forward when the cart was stopped to a cessation of the force holding it at the back while the cart was moving.

### C. Task 3. Inertia in Space

While the other tasks were in random order, this task was presented last to observe any transfer of concepts of inertia from terrestrial to interplanetary space, which could be inferred in the context of the responses to this question. A globe of the earth and models of a spaceship and a spaceman were presented. The spaceship with the spaceman inside was shown orbiting the earth in a path over the north and south poles. The student was then asked "If the spaceman went outside the spaceship to make repairs without a life-line and let go when the spaceship was over the equator (moving north) where will he be when the spaceship is over the north pole?" The student was asked to explain his answer. The student was then asked, "If the spaceship was not in orbit but out in space and the spaceman did the same thing, but *pushed* away from the spaceship, what would happen? Is there any way he could get back?"

Since the spaceman in orbit has the same velocity as the spaceship and there is no retarding force, the spaceman will continue with the same velocity as the spaceship. He will also be equally effected by the gravitational pull of the earth, being smaller in mass but having a correspondingly smaller force acting on him. So the acceleration towards the earth will be the same and he will continue alongside the spaceship.

When out in space, away from external gravitational fields, if he pushes away from the spaceship, he will

continue in the direction of the push (and also give an equal momentum to the spaceship in the opposite direction). He could return to the spaceship if he threw something very hard in the opposite direction from that in which he wishes to go. The force must be great enough to counter his first motion and change it to the other direction. He could also use some small jet propeller.

Unfortunately, the first part of this task often stimulated enough discussion that the validity of some of the students' replies to these later questions is in doubt. The responses to the second part will not be reported unless there had been no discussion and only if the student's response in this part might throw light on his reply to the first part.

This task tests the degree to which the students conserved motion when the spaceman left the spaceship and their perception of the motion of the spaceman relative to external frames of reference when he is in the spaceship.

'Coordination of two systems of reference and the relativity of motion' and 'the forms of conservation which go beyond direct empirical verification' are two of the eight operational schema described by Piaget (Inhelder and Piaget, 1958, p. 307-329). These schema together with correct knowledge about conditions in space would direct the student to place the spaceman over the spaceship.

It is doubtful whether any students could give an intuitive response to this task, at least not one that would

conserve motion. They have never been in space so their replies will depend on the schema they have developed based on vicarious second-hand experience from television and space-science.

The students' replies to the questions will be reported first and then some miscellaneous preconceptions which the questions revealed will be described.

#### Destination of the Spaceman in Orbit

Table 5 shows the frequency of occurrence of the various predictions for the position of the spaceman when the spaceship is over the North Pole. His possible location would depend on what speed the student assigned to him and whether the student considered the spaceman would be affected by gravity and to what extent. Some students also took into consideration other factors such as whether the spaceman would have air 'to give him buoyancy'.

A cursory glance at Table 5 indicates that girls are more likely than boys to expect the spaceman to remain over the equator. Boys are more likely than girls to expect the spaceman to remain with the spaceship. Neither tendency is significant at the .05 level.

Almost half of the students placed the spaceman over the equator that is, with no horizontal motion. The problem is similar to the ball in the cart when the cart suddenly

Table 5

Distribution by sex of total occurrence of predictions  
of destination of spaceman in orbit

	<u>Per cent responding</u>		
	Boys N=26	Girls N=14	Total N=40
<u>At same speed as spaceship</u>			
With spaceship	50.0	21.4	40.0
Above spaceship	3.8	0	2.5
Total giving spaceman same speed	50.0 <sup>a</sup>	21.4	40.0 <sup>a</sup>
<u>Slower than spaceship</u>			
Dragging behind	38.5	57.1	45.0
Moving outwards	11.5	0	7.5
Spiralling towards earth	15.4	7.1	12.5
Total expecting retardation	50.0 <sup>a</sup>	57.1 <sup>a</sup>	52.5 <sup>a</sup>
<u>Staying over equator</u>			
Floating or stationary	26.9	50.0	35.0
Floating away	0	7.1	2.5
Toward earth	19.2	7.1	15.0
Total expecting no linear motion	38.5 <sup>a</sup>	64.3	47.5 <sup>a</sup>
<u>In reverse direction</u>			
Down to desk	11.5	0	7.5

<sup>a</sup>Some students altered their replies by changing the effect of gravity so this is not the total of replies but is the total number of students giving this reply.



stops. Of the nineteen who expected the spaceman's horizontal motion to stop when he let go the spaceship, more than one half had explained the motion of the ball in the cart by a force or cessation of a force. For example, Tim said,

*It could be when you're going the wind pushes it back then when you stop there's no wind so the sudden stop pushes it forward.*

When asked where the spaceman would be, Tim said:

*Same place where he fell off. He wouldn't be moving it was the spaceship that moved. He'd just stay in the same spot.*

On the other hand, Gordon, discussing the ball in the cart said:

*When you stop the cart the ball would have still been going like since you pulled it you've got the ball going that speed and when you stop the cart, you haven't stopped the ball so the ball hits the front.*

For the spaceman problem he said:

*He'd still be over the equator because there's no motion. He has no movement. Like the spaceship is propelling itself through space and he has no way to do that so he would just stay still.*

When reminded of his reply about the ball in the cart Gordon said:

I'm not sure like here, with the ball there's - it's - the difference between there and space is, so much different like there's pressures and things like there's higher pressure, the closer you get to earth. It gets lower as you go up and that means there's lower - I don't know in space. To me, I would first think he would just sit there and then you know, you compare it to that but then out in space -

In Piagetian terms, Gordon is seeking an equilibrium between the sub-systems of schemes: His ideas of space, both those previously acquired and his intuitive response to this question and his schema about the ball in the cart present conflicts which are not resolved during this interview. Although Aristotle was more limited in his knowledge of matters beyond his own experience, he also believed that conditions in space could be different from those on earth.

Of the twenty students (one half of the sample) expecting the spaceman to lag behind the spaceship, seven students mentioned that the effect of gravity on the man and spaceship would be different so the spaceship would be pulled round faster because it is heavier. This is particularly surprising after Task 1 where 6 of these students had expected the large ball to go slower and stop sooner. The other of these 7 students had expected no difference with the balls. The 3 boys who thought the spaceship was pulled

round faster were each hesitant about the idea - more so than the girls. Again, this is an Aristotelian concept - that gravity has less effect on a smaller object.

Another explanation for the spaceman lagging behind the spaceship given by thirteen students (three of whom also thought gravity would have less effect on him), was that the spaceship was powered in some way or was 'programmed' to circle the earth. They were projecting conditions on earth into space.

It might be expected that the students who decided the spaceman would be over the North Pole would be both conservers of motion and comprehend the nature of the motion of the spaceman and spaceship when together. It appears that this was not always true. Shawn, for instance drew an analogy between space and earth which seems to reveal non-conservation:

S. *When it's orbiting the earth, it's not as if it's up and down and all of a sudden 'it goes off like that. It's not as if it's upside down when it's going underneath the South Pole there. It stays flat like that. Why? I don't know. Maybe because of the speed, it's not going to fall off because if you stand up on a car when it moves forward and you're on the hood of course you're going to be likely to be jerked off. If you're kinda on there stable you know, you're going to*

stay on - it's moving over a flat surface so he should have no trouble staying on.

Shawn apparently did not expect that the spaceman would stay with the spaceship if he fell off. He was non-specific about why the spaceman would stay on the spaceship - maybe gravity, maybe because it is not upside down. What part speed plays is also uncertain, whether it causes a centripetal force or just produces a more stable situation. Later, when Shawn was asked about the spaceman pushing himself off in space, he said:

S. *There's no gravitational pull. I guess he'd just float upwards because there's nothing pushing him down to the sun.*

I. *Would you like to take him and show me what would happen?*

S. *He'll drift up there I guess.*

I. *Will he go on? Is he going to stop?*

S. *No, he'll be kind of suspended in space. I guess.*

I. *Will he stop like that or will he go on?*

S. *No, I don't think he'll go on.*

I. *Where will he go?*

S. *To the extent of his force. After it's gone he'll kind of just float.*

I. *He'll just stay around? What do you mean by the extent of his force?*

S. *How hard he pushed off the ship I guess would*

*determine how far he'll move off.*

I. So if he gave a really hard push he'd go further than if he gave a light push?

S. *Actually, I don't know, you know, because the gravity you know. Maybe it doesn't make any difference how hard he pushes himself off. Perhaps he'll just move a certain distance and stop there. Maybe he'll go like that and the ship'll move right along.*

In this dialogue Shawn certainly seems to have no concept of conservation of motion. However, lack of conservation of motion in this instance only suggests that he did not conserve motion when the spaceship was in orbit. Many students were inconsistent in this respect and lack of conservation of motion cannot be assumed to be proven absent.

Two students expected the spaceman to be above the spaceship. Alan reasoned that:

A. *Oh, probably a little further out but he's still orbiting the earth. Like gradually, eventually, he's going to straighten out.*

I. Why?

A. *He's a lighter object, something like that. It's got something to do with gravity, I know that.*

This argument is similar to expecting him to slow down because a smaller force of gravity acts on him. Again, this

is an Aristotelian idea.<sup>7</sup>

Greg eventually placed the spaceman with the spaceship. Before doing so he expressed a rather unusual viewpoint:

G. *He'll be up here somewhere.*

I. Why do you think he'll be up there?

(In the lab setting, "up there" was level horizontally with the North Pole and above the equator.)

G. *Because there's no gravity so he'll start to float so if he's up there the ship is on an angle like that he'll start floating up like that.*

I. Why will he move up there?

G. *Because there's no gravity to hold him down so he'd float in the space.*

I. Why will he move? (Pause of ten seconds) Why is there no gravity?

G. *I can't tell you.*

I. If there was gravity which way would it be pulling him?

G. *Toward the earth.*

I. But there is no gravity.

G. *So he'll probably be floating away.*

I. Why does he go in that direction?

---

<sup>7</sup> If the spaceman were "above" the spaceship, that is, on the other side of the ship from the earth, when he let go, then his centre of mass would be further from the earth, the gravitational force would be less and he would have a slight tendency to move out but this would soon be corrected he would in fact have a slightly disturbed orbit.

G. *If the craft was like that, (moving on around) and he was like that, he'll probably go straight up, I think.*

I. *Why does the spaceship go like that? Why doesn't it go straight on?*

G. *Because it's being pulled in by the earth's gravity.*

I. *But you said there was no gravity up there.*

G. *Then there must be gravity up there.*

I. *What will the spaceman do then?*

G. *Then he'll probably go in the same direction.*

I. *Where will he be then?*

G. *He'll probably be right over it. (the spaceship)*

From this last remark, Greg appears to be capable of conserving motion but his previous responses indicate that other thought patterns predominate in his cognition. First, he has confused frames of reference. Greg thinks the spaceman will float - upwards (being weightless?). Another preconception which this interview illustrates is the confusion between inertia and gravity. When Greg accepts that there is gravity up there, *then* the spaceman goes with the spaceship. The same preconception has been observed earlier where students decided the spaceman would go slower than the spaceship because the force of gravity on the spaceman was less. The same idea was evident in Task 2. For example, in Geoff's explanation where 'the weight, the momentum and the gravity' are all used to explain the motion of the ball forward when,

the cart stops.

The pattern of Greg's replies to Tasks 1 and 2 were similar, he responded first with primitive ideas but after discussion on both, he was able to give explanations consistent with conservation of motion.

Referring back to Greg's original prediction, we have the spaceman floating *upwards* where 'up' is in reference to the field of the laboratory. He was not the only student to confuse frames of reference. Brian, amongst many replies which he attempted said he would be 'down there' pointing to the desk supporting the globe. In later discussion, both Greg and Brian indicated that they knew that gravity pulled towards the earth. It appears that the more primitive idea of gravity acting *downwards* is intuitive whereas knowledge that gravity pulls *towards the earth* is acquired and is not so ready a response.

Harold had this problem of orientation and much more besides. His first remarks indicate great uncertainty about the problem. (sic)

I. Where is he going to be?

H. *He let go the whole spaceship? So he's apart from the spaceship?*

I. He was here and he just let go.

H. *So he let go of the whole thing?*

I. He wasn't catching hold of it at all.

H. *O.K., I got it now. When the spaceship's up there, where is he?*



I. Yes.

H. *He should be floating up.*

I. Where?

H. *Into orbit.*

I. The spaceship's here, would you like to put him where he'd be?

H. *No, he'd be going down.*

I. Down? To the desk?

H. *Yeah, down to the desk.*

I. Why would he be going there?

H. *Because if he never attached his life-line then that takes all his oxygen away.*

I. He has his oxygen in the back there.

H. *So he's breathing oxygen?*

I. Uh-huh. He couldn't survive without that in space.

H. *O.K., then he'd be going up.*

I. Uh-huh.

H. *Because gravity is real light, it can push you around like this. If you see a guy in a movie he floats around so he could be floating around, up there.*

I. Why will he go up there? The spaceship was going like that in orbit. Why would he go in that direction?

H. *Well, since gravity's so light it pushes you up. Gravity comes under you and pushes you up.*

*that's what makes you go up.*

I. Uh-huh. What does gravity do to you?

H. I don't know.

I. What is gravity doing to you at the moment?

H. Nothing - I'm sitting.

I. Nothing at all?

H. Well, it's pushing under me trying to get me up but can't.

I. Supposing there was no gravity at all, what would you do?

H. I'd be sitting on the ground all the time.

I. Would you?

H. Well, I'd be walk - I'd be on the ground the whole time.

I. What keeps you on the ground?

H. Your force.

I. What force?

H. Well, the force that makes - when you walk, you push force down on the ground and that makes you walk.

I. Well, why do you stay on the ground? Why is it you can't jump up in the air?

H. Well, you could probably jump but you'd come straight down.

I. Well, why is it you can't go further up? What keeps you down?

H. Well, your force. When it goes up, your force

*pushes you down again. Well, gravity tries to push up and your force pushes you down. Your force is heavier than the gravity so it pushes you down on the ground.*

I. Isn't gravity what keeps you down on the ground?

H. No, I think that makes you get up.

I. Why do you think it makes you get up?

H. Well, it's just, gravity's so light it pushes up and it's just like (if you leave it?) it's so light and if you put it in a balloon it goes up. So it pushes up. (Could he mean 'levity'?)

I. What do you think gravity is? What is it due to?

H. I think it's just an air mass or so pushing up.

I. Why does the moon keep in orbit around the earth?

H. Why does the moon keep in orbit around the earth? I don't get what you mean.

### **Some Miscellaneous Beliefs**

While conservation of motion and understanding of relative motion were essential to complete success in this task, it was also necessary to have knowledge of conditions in space such as the lack of an atmosphere and the effect of the earth's gravity. Students often gave evidence of preconceptions in this area. Some of these preconceptions are derived from poor quality science fiction which takes little cognizance of the scientifically accepted framework of

knowledge.

In order to know that the spaceman would keep with the spaceship, the student must know:

1. That there is no air to produce friction.
2. Something about orbits
  - a. The spaceship has no engines. Its speed is conserved, the direction only is changed by the effect of the earth's gravitational field.
  - b. Centripetal force is provided by gravity.
  - c. The force of gravity is proportional to the mass and its effect on all objects is the same.

#### **Engines in the spaceship**

Although no mention of the method of propulsion of the spaceship was made by the interviewer, almost half (seventeen) of the students during their discourse volunteered the information that the spaceship had engines or rockets. One other student thought that the spaceship was "programmed" to circle the earth when it was in orbit. Believing either of these, it would be logical to assume the spaceman would lag behind the spaceship.

#### **Problems with orbits**

Many students had a confused idea of what orbiting the earth meant. Doubtless few had considered the matter before. David's interview illustrates several of these preconceptions. David predicted the spaceman would be above the equator

I. Here?

D. No, he wouldn't be. Okay, if the world's turning and the spaceship going this way, he falls off the spaceship?

I. Well, he just lets go.

D. Then he's still on it.

I. He was here and he just let go the spaceship where will he be when the spaceship's up here?

D. Over the equator.

I. Will he stay there?

D. Yeah, he'll stay there.

I. Just up in the sky?

D. No, because he's in the earth's gravitational pull in a strict orbit. He can't get in or out.

I. Why?

D. Because the grav - equal forces, the gravitational pull of the earth.

I. Wouldn't that pull him down to earth?

D. No, not if he's in orbit with the earth. Like the moon's not being pulled down to the earth because it's in orbit with the earth and the gravitational pull is equal with the ...

I. With what?

D. I don't know.

I. You know there's a gravitational pull pulling him inwards, there must be something pulling him outwards. Why does the moon stay up there?

- D. Maybe because of its own gravitational pull.
- I. What does a pull do?
- D. Keeps them apart.
- I. Why would the spaceman stay here? What about the spaceship? Why does it go on moving?
- D. O.K., the earth is turning, right? It's like the spaceship keeps going around it in orbit. If there's no gravity in space but there is the gravitational pull of the earth and from the sun and the spaceship gets in orbit between the earth and the sun, well, between the earth, round the earth and because the gravitational pull from the sun and the earth, it equalises it so it can't go up or down unless it's own power.
- I. What about the spaceman?
- D. Same rules when he stays up
- I. So he stays here because the earth is pulling him down and the sun is pulling him?
- D. Pulling him away. The forces are equal so he stays.
- I. Suppose this happened when the sun is over there?
- D. He's in a lot of trouble. He would stay where the sun is all the time because the earth is turning this way. He's here, the earth keeps turning round and round, he stays but doesn't go anywhere else.

David has a schema of a spaceship orbiting the earth by the earth turning beneath it. This idea could have been suggested by the discussion of fixed position satellite transmitters. Then it is quite logical that the spaceman stays with the spaceship. When it was pointed out that the spaceship moved over the North Pole (which would not be possible if the rotation of the earth caused the relative motion) David, lacking conservation of motion, left the spaceman over the equator. David postulates an orbit as something physical in order to explain why the spaceman should stay there. Asked to clarify, he sought a balancing force in vain. He appealed to the fact of the moon remaining in place suggesting its own pull held it there. Perhaps because the gravitational pull of the spaceship wouldn't be large enough to hold it there in the same way, he introduced the idea of the sun's gravitational field as the necessary force.

David's idea of the moon's gravity holding it up is similar to Piaget's young students (about seven years old) who thought, (Piaget, 1930, p.250)

An object floats because, being heavy, it has the strength to keep itself up.

Chris also had problems with conditions in space. She first thought the spaceman would follow the spaceship because of the 'airstream' (reimniscent of Aristotle imagining continued motion being due to the motion of the air).

*From the airstream from the jet, it's moved and it's pulling the air along with it so he'd be moving along too.*

Chris thought the moon stayed in position because of the sun.

Tim first thought the spaceman would stay over the equator but when reminded of the ball in the cart he put him somewhere behind the spaceship:

I. Where?

*T. Could be - if he was trapped in the orbit, he would go round the earth but if there was no gravity he would just keep going straight.*

This is again an idea of a fixed orbit.

Richard thought the spaceman would spiral into the earth because he lost momentum:

I. How does he lose the momentum?

*R. He wasn't in the ship and he'll probably fall below the orbital line going down.*

This again suggests a physical orbit. When comparing the spaceship with the moon and asked if the moon was powered, he said:

*No, it just orbits. It's far enough away from the earth not to be pulled into it but close enough to be moving around it.*

Like David, he doesn't feel the moon would be pulled by the force acting on it.



Claren had a similar idea. In spite of problems with English as a second language, she was able to express her thoughts well enough. She thought the spaceman would float around, over the equator but

*He is going to still stay up there because the earth's gravity doesn't attract that much in the atmosphere*

As proof, she mentions the moon:

*For instance, if a moon has gravity to earth but it doesn't land on earth does it. It just revolves around earth, well earth attracts it but the moon doesn't land on earth.*

She does not mention perhaps does not notice that, while the moon is moving, her spaceman was not.

Bill also felt the need for a force:

I. Do you know why the spaceship is orbiting?

B. *Because it's between two gravity forces, moon and the earth.*

Gordon also carries lack of conservation of motion into the rotation around the earth's axis:

I. Would he stay right above the equator?

G. *No, because the earth is moving itself so he'd stay in that spot but the earth would be moving.*

From these examples it can be seen that some students who lacked conservation of motion not only expected that the spaceman would be left over the equator but thought that the world turned beneath him and beneath the spaceship. It was

also possible for students who did not understand circular motion to present an orbit as something almost physical. Some students expected a body far enough away from the earth to stay suspended in space even though the body was not moving and was being acted on by gravity. Other students seemed to think it was possible for the sun's gravitational attraction to balance the earth's.

### Gravity and air

In the view of Newtonian mechanics, there are at least three occasions in space travel when an astronaut is "weightless".

1. When he is so far from other objects that their gravitational fields are negligible.
2. When he is so placed between two large objects that the gravitational field of one is exactly balanced by that of the other. For example, at a fixed point between the moon and earth, closer to the moon than the earth. Since the ratio of the sun's mass to that of the moon is eighty-one to one, the distance from this point of equal gravitational force to the sun will be nine times greater than the distance to the moon.
3. When he is in orbit around an object. He is in constant free fall under the gravitational field but has just sufficient horizontal velocity to remain in orbit. This is a more difficult concept to understand especially before studying the physics of circular motion.

Most students knew there was no gravity in space but were not always sure where the effect of the earth's gravity ended. For some this caused confusion with the weightlessness of an astronaut in orbit round the earth. They assumed he weighed nothing because he was out of the earth's gravitational field or sometimes even when they knew there was a gravitational field. For instance, Paul said:

*He just isn't heavy enough to be pulled back as well. It must be there (gravity?) because the moon is attracted to the earth but he just couldn't move forward because there's no - because he's not really - doesn't really weigh anything in space.*

This is another instance of the spaceman not being able to move forward because he weighs nothing.

Some confusion due to the idea of a spaceman in orbit being weightless was apparent: Two girls mentioned that he was weightless even though they thought he would be stationary and one boy said the man weighed nothing but the spaceship was affected by gravity. In space travel it is the spaceman who is described as being weightless, not the spaceship. This is possibly why some students thought that gravity was acting on the spaceship and not on the spaceman.

There was also confusion<sup>2</sup> for some students about the relationship between the atmosphere and gravity. Several students thought there could not be one without the other and explicitly stated so. Since they knew the atmosphere ended somewhere above the earth and so did gravity, perhaps

they thought that if the earth had a sphere of gravitational influence, it would be occupied by air. Some indicated that they weren't very sure what gravity was. It was sometimes described as though it were some mysterious force which held things in place. For instance, Tamara seemed to think gravity would do more than just pull towards earth:

*T. Because there's gravity it stays in its orbit. The earth has gravity, it's kind of holding it there, I guess.*

*I. What does gravity do?*

*T. Holds things where they're supposed to be, I guess.*

*I. What does it do to you when you try to jump off the ground?*

*T. It holds you down to the ground.*

Another student, predicting that there would be no gravitational force acting on the spaceman or the spaceship thought that there might be a magnetic attractive force between the spaceship and the earth. Barb said:

*B. He's out of orbit so he's not in with the gravitational pull of the earth?*

*I. He's here on the spaceship which is in orbit.*

*B. Out of the gravitational pull of the earth, it's not affected - well I don't know if it is.*

*I. Why does it go in orbit round the earth?*

*B. Because the earth pulls it together, magnetic poles?*

I. Magnetic?

B. *Gravitational pull pulls it to the earth.*

Many students, like Tamara, described the spaceman as "just floating. That's the way they show it on television." In the absence of direct experience, television will provide for many students their only cognizance of space. Some students, like James, seemed able to criticize such shows. In discussing where the spaceman would be if he let go of the spaceship in orbit, he said:

J. *I should say he doesn't have to (hold on). He might drift a little ways in relation to the spaceship. But on the space-shows you always see the guy drifting away the minute he lets go.*

I. You don't think that's right?

J. *I don't know if it's right or no. There's a lot that's not right in those space shows. No, I don't think it would make much difference if he wasn't holding on for a few seconds. I don't think he'll drift very far though.*

I. Why?

J. *Because he's in - he's moving in relation to the spaceship the same as the spaceship is when he's holding on. So he should keep moving the same way after he lets go.*

James was the only one to score full marks on the criterion test and had seventy six per cent in end of term marks.

Other students who seemed uncritical of television, did not

do as well in physics.

**Space as a venue.**

Space presents an entirely different venue for students. Their conception of space at the beginning of grade X ranges from surprisingly sophisticated accounts of centrifugal force (all these from boys in this project) to some more primitive and imaginative. Their preconceptions are often fabricated from the various reports they have heard and read on space travel and from space shows and science fiction.

Except for those students who were actively interested in space science, mostly boys in this study, most of the students interviewed disclosed only some isolated and not always accurate knowledge of space travel. Answering the questions posed necessitated their combining some items of information which they had acquired about space together with their understanding of motion on earth. The inherent complication of constant resistance to motion on earth which prevented easy analogy with space made the task more difficult. Unless they were aware of certain facts such as that there is no air in space but there is a gravitational field where a spaceship is orbiting and were able to combine them logically, the task was very difficult.

The average time of response to the question "Where will the spaceman be when the spaceship is over the North Pole?" was greater than the average response time to any

other question. After predicting the position of the space-man, the wait time for the reply to the request for a reason for that prediction was less than for the other questions. Five (of thirty two) students explained their first answer as they gave it before being asked for the explanation. This wait time is needed for the student to think about the images and concepts which might be of use in this situation and to combine them to form a logical conceptual framework sufficient to answer the question. Having answered the question, the explanation has already been formed.

The students do not have such a wealth of physical experience of space on which to draw as they do for terrestrial problems. Because of the absence of resistance, it should be easier for students to construct a simple framework within which to think about simplified frictionless motion in space than studying motion on earth, especially if taken away from the complicating factors of orbiting the earth.

It is suggested that "space" is a useful tool in teaching by providing illustrations of Newtonian mechanics. It has the added advantage of being an area which appeals to many students. Obviously events in space are not advisable when introducing motion because they are not familiar and do not provide tangible examples. But concepts can be dealt with in the context of earth first and then later related to events in space especially those which become reported in space research or by reference to heavenly bodies.

Table 6 gives the distribution of the first replies of the students. Comparing figures with Table 5, the later replies tended to place the spaceman either with the spaceship or closer to it. There is a significantly larger proportion of girls than boys who suggested the spaceman would remain over the equator when first responding to the question where the spaceman would be. However, if considering the response as being the most primitive, the two boys who suggested the spaceman would go in the reverse direction should be included. This gives chi-square for distribution by sex of the most primitive answer as 3.24 which is not significant at the .05 level.

#### Summary

Almost half the students expected the spaceman to stay at the equator. Only half of the remainder of the students predicted he would stay with the spaceship.

Three students failed to see the globe out of context of the laboratory for a little while thinking of gravity acting "downwards" rather than towards the earth.

Nearly half of the students thought that the spaceship was propelled by engines or rockets when in orbit while one other student described it as being "programmed" to circle the earth. Some students thought the world turned underneath the spaceship.

There were many misconceptions about gravity. Among them were:



Table 6

Distribution by sex of occurrence of predictions of  
destination of spaceman in orbit. First reply

	<u>Per cent responding</u>		
	Boys N=26	Girls N=14	Total N=40
<u>At same speed as spaceship</u>			
With spaceship	34.6	7.1	25.0
Further out than spaceship	3.8	0	2.5
Total	38.5	7.1	27.5
<u>Slower than spaceship</u>			
Dragging behind	19.2	28.6 <sup>a</sup>	22.5
Moving outwards	3.8	0	2.5
Spirally downwards	3.8	7.1 <sup>a</sup>	5.0
Total	26.9	35.7	30.0
<u>Staying over equator</u>			
Floating or stationary	23.1	50.0	32.5
Floating away	0	7.1	2.5
Moving toward earth	3.8	7.1	5.0
Total	26.9	64.3	40.0*
<u>In reverse direction</u>			
Down to desk	7.7	0	5.0

<sup>a</sup>One girl thought the spaceman would follow the spaceship for a while then spiral towards earth. She is counted twice.

\*For this distribution by sex,  $\chi^2=5.29$ ,  $.02 < p < .05$

- a. There is no gravity because the spaceman is weightless.
- b. There is no gravity because there is no atmosphere.
- c. Gravity acts on the spaceship not on the spaceman. In space travel it is the man who is described as being weightless, not the spaceship.
- d. Gravity is sometimes used as the "force forwards" similar to inertia. If this force is less because the spaceman is lighter, he goes slower. If gravity is absent, he does not continue forward.
- e. The spaceman can remain stationary above the earth in the earth's gravitational field without being pulled to earth because the moon does not move to earth. There are various reasons for this including balancing gravitational forces from the moon or sun or there is no reason at all.

Except for those boys who had studied space science as a hobby, most students' ideas of space were strongly influenced by television and science fiction. At least one student expressed scepticism about the veracity of space science but others in saying: "Well that's the way the spaceman floats on television" were expressing some possible doubt.

#### D. Task 4. Acceleration Produced by a Constant Force

The three previous tasks were concerned with students' understanding of the inertia of stationary and moving objects, that is, with Newton's first law of motion. The fourth task deals with accelerated motion: Newton's second law. Its inclusion in the project was an attempt to discover whether there was any relationship between the distribution of understanding of inertia with that of accelerated motion.

In this task, a cart was attached by a string over a pulley to a hanging weight and the student was asked to predict what would happen if the cart were let go. When the student had predicted a movement of some type, the cart was let go and the student was then asked what type of motion he perceived and, if he could, to explain this motion. Next, a longer string was attached between the cart and weight and the student asked what difference, if any, this would make and "Why?"

The force of gravity acting on the weight is translated into a horizontal pull on the cart by the tension in the connecting cord. If this pull exceeds the frictional forces opposing its motion, the cart will move toward the pulley with a constant acceleration. The size of this acceleration will be dependent on the unbalanced force acting on the cart before it hits the pulley.

The acceleration can be explained in various ways: It may be considered that it is the constant pull on the cart which produces the steady increase in momentum of the cart,

that is, acceleration. Alternatively, the potential energy of the weight which is lost as it falls, may be seen to be transferred to the kinetic energy of the system of weight, cord and cart.

When the string is made longer, the cart moves in the same manner until the weight reaches the floor when the only forces acting on the cart will be frictional and it will continue with a very slightly decelerated motion to the pulley.

#### Explanation of Acceleration

Table 7 gives the distribution of the student explanations for the perceived increase in speed.

There seemed to be three explanations for the acceleration which were equally favoured by the thirty three students who attempted to answer this question:

Almost one third (11) of those replying thought that the speed increases because the force of gravity increases near the earth. They are, in effect, saying that there is a linear relationship between force and velocity or

$$F = K \times V$$

It is possible that some of these students were aware that gravity decreases with distance from earth so perhaps they thought that its increase on approaching earth must be sufficient to explain the increase in velocity. Geoff may have had this idea when he said: *Because the closer you get to the ground, the more gravitational pull there is.* If this was their way of thinking, most of the students suggesting

Table 7

Distribution by sex of occurrence of concepts explaining  
acceleration of cart pulled by constant force

	<u>Per cent responding</u>		
	Boys	Girls	Total
Reason for acceleration	N=25	N=14	N=39 <sup>a</sup>
Pull of gravity greater near earth	28.0	21.4	25.6
Falling body increases speed	44.0	7.1	30.8*
Speed or energy increases	28.0	28.6	28.2
Don't know	0	42.9	15.4**

<sup>a</sup>One interview was not recorded on tape for this task.

\*  $\chi^2 = 4.12$ , for distribution by sex, corrected for small expected frequencies.  $p < .05$ .

\*\*  $\chi^2 = 9.58$ , for distribution by sex, using Yates correction for small expected frequencies.  $0.01 > p > 0.001$ .

this explanation did not perceive that any such increase must be so small as to be negligible even if this relationship were true. One might suspect that in some cases this idea of the increase of gravity near the ground was only introduced to the students' thoughts by the question. It may not have been present before. The result obtained here is similar to one obtained by Aguirre (1978) where half of the students interviewed, ages six to fourteen years, said that a washer is heavier closer to the ground. This terminology seems to be similar to that of Piaget's young students. Piaget describes their response (Piaget, 1974) "From the fact that the weight tends to go down vertically, the subjects of (stage) IIB will conclude, for example, that it acts and weighs more toward the bottom than the top" (P. 92).

In this present study, with older students than either Piaget or Aguirre interviewed, only one student talked about the weight getting heavier. Bernie said:

*B. There will be acceleration, speeding up of the cart and at first it won't be doing anything right at first and then the lead weight will be getting heavier and heavier and it'll be actually pulling - no the gravity would be pulling the lead weight down towards it.*

Another one third explained the increase in speed of the cart by its attachment to a falling body so that

$$\text{velocity of cart} = \text{velocity of falling weight}$$

The remaining one third of the students replying seemed to possess a more scientifically acceptable idea, either that the continuing applied force overcomes inertia and constantly increases the speed of the cart (9 students) namely,

$$F = K \times dV/dT$$

or that potential energy is converted to kinetic energy (2 students). Such views were interpreted as being expressed by the following statements:

1. It takes a little while to get started and then it just keeps going. Like this thing fell all the way and it keeps falling so that would even pick up more speed.
2. The gravity just pulls it faster and the thing falls faster.
3. It will start slow because it's got to overcome that inertia and then it'll start gaining speed.
4. In the beginning you need more force to get rolling and then it starts moving and doesn't need as much force and it makes a greater movement on the ball.
5. First the car will be moving slower and as it speeds up it will be freer to be moving faster.
6. It started going faster when it was going down so the gravity started pulling down more so the whole thing

*starts speeding up.*

7. *The gravitational pull on this will make it speed up.*
8. *The gravity will be pulling on them and the more it's pulling the more they'll fall faster.*
9. *When the weight is falling, it increases in momentum and the faster it falls the more energy it carries.*
10. *It gains energy as it's falling.*

That only two students mentioned energy as a possible factor is surprising since energy is in the Junior High School curriculum.

During the time in which the interviews took place, a change in the relative frequency of occurrence of the replies to this task appeared to take place. Of the twenty students interviewed in the first seven days of the interviews, nine said the cart went faster because the pull of gravity is greater near earth and only three students said it was because a falling body goes faster. Of the twenty students interviewed in the last eight days, three gave the former reason and nine the latter explanation. A chi-square test gives a probability of such a distribution occurring by chance as less than 0.05 and greater than 0.02.

From the comments of students it seemed that more schools were dealing with the motion of falling bodies in the curriculum as the interviews continued. The recency of this topic in class may be a reason for the increase in frequency of explaining the acceleration by the acceleration of a falling body. It suggests that with these students, their



replies may have been affected by external events. Harold gave an Aristotelian explanation at first:

I. Why does it go faster as it goes down?

H. *Because its weight - the air pushes it back like this, forward and this just goes down because the weight pushes it down. So the faster it goes - so wait a minute, when it goes down, it goes down slowly and then it goes faster and faster.*

I. Why is that?

H. *Because when air pushes it this way, see it gathers it in like a vacuum or something. It pushes that way.*

I. And that makes it go faster?

H. *No, I don't think so.*

I. Why does it go faster?

H. *Because this is falling down and it pushes it.*

Harold seems to be suggesting that the air swirls around the cart and pushes it. This helps to increase the speed of the falling weight and the cart. Aristotle believed that violent motion, (not natural), was sustained by a similar action of the air.

#### **Predictions of Movement.**

One third of the students predicted that the cart would not move unless the weight was heavier than the cart. When the cart moved, four of these thirteen students remarked that the wheels made a difference, the others made no comment. Without wheels the force of friction between the

cart and the table, which has to be overcome by the tension in the string before the cart will move, would be very much greater. The cart would not move in this case. With the task as presented, there was very little friction either in the rotation of the wheels or between the wheels and the table.

#### **Type of Movement**

Robertson and Richardson (1975) in similar work with Grade 9 and 10 students found that all boys and ninety per cent of the girls tested recognised a change in speed of the trolley (acceleration). In their experiment, similar apparatus was used and the students were asked to note the speed of the cart as it passed two vertical lines on cards placed one meter apart. They were asked whether it was the same and ninety per cent of the students recognised a change in speed. (P.327) In this present study, nearly the same proportion, 84.6% predicted a constant acceleration. Of the remainder, only one boy failed to recognise a constant acceleration in the demonstration. He saw an acceleration to the mid-point, then a constant speed.

#### **Effect of Longer String**

Thirty students predicted that lengthening the string would have no effect on the movement of the trolley. Two students, not noticing that the weight would reach the ground before the cart reached the end of its run, thought the cart would reach a greater speed because the weight would be pulling for longer. Seven students thought that the

cart would have a smaller initial speed when it was longer. To quote Deborah: "because it began further back" and:

*D. I don't think it will go quite so fast.*

*I. Why not?*

*D. Because there's a longer rope here. It's taking longer to get to the cart.*

### Summary

Understanding the concept of acceleration presents no difficulty to students of this age.

The concept of energy was used by five per cent of the students to explain acceleration. The remaining explanations for acceleration could be divided almost equally into three groups:

1. The force of gravity increases near the ground so the force on the cart increases.
2. A falling body accelerates therefore the cart will also.
3. The continued application of force overcomes the inertia of the cart and increases its speed or momentum.

These ideas on motion are easily effected by external influences such as instruction in class.

One third of the students thought initially that the hanging weight would have to be heavier than the cart for the cart to move. Twenty three per cent of the students thought that a longer string would mean that the cart would have a smaller initial speed. That is, they lacked conservation of force.

## Chapter V

### AGREEMENT BETWEEN ASSIGNED LEVELS

Many researchers have pointed to the problems associated with applying cognitive stages to individual students from interview protocols (Hobbs, 1977). In dealing with groups of children and studying their development as a group, Piaget was dealing with a much more stable element. The individual will shift his ideas from time to time during the course of the interview but the group as a whole will remain within certain limits.

The changes which the student makes during the interview will reflect his internal cognitive processes and also the interaction of these with external stimuli such as the remarks made by the interviewer and also the non-verbal communication which takes place. Attempting to separate these is an impossible task; yet to attempt the same diagnosis on written answers and even more so with multiple choice tests has the disadvantage of losing depth. In short all attempts to investigate the students' cognitive functioning must choose between incomplete information and overmuch.

Another problem in assigning stages is in deciding on the criteria to use. In this study, Tasks 1, 2 and 3 were assessed at least twice. In each case, there was moderate correlation between the assigned levels for each student between tasks ( $r = 0.6$ ) but not the same agreement across

tasks or with achievement.

Another problem with any method of determining cognitive stages is in understanding the student's meaning, especially if his ideas are very different from those of the investigator.

The assignment of cognitive stages is often taken to describe some innate characteristic of an individual. Now, although maturation must be an important factor in the manner in which a student responds, his experience or learning must play a part. Piaget describes the interaction of the environment and the cognitive structures of the organism as an essential process in development. So, in this case, the cognitive stage of these students will be affected by previous experience as well as by innate characteristics more so than with the younger students with which Piaget worked. This is not important in this study; the cognitive stages are used to compare replies on the various tasks and to discover whether these have any effect on achievement in physics.

#### A. Distribution of Cognitive Stages

##### Task 1. Horizontal Motion along a Groove

The first task in this study in which balls were propelled along a groove is similar to one developed by Piaget (Inhelder and Piaget, 1958). Piaget, however, interviewing younger students, employed several balls of different masses and sizes and posed the questions "which

will go further" and "why". In the present study, initially only one ball was used and then three balls of different sizes and masses. The student was asked more open-ended questions: "What would happen when the first ball was propelled along the groove" and "Why?" and "What difference would there be with the other two balls?" Within the context of the Piagetian interpretive framework, the results resemble those obtained by Piaget and are conveniently classified in a similar fashion. Piaget and his co-workers grouped the responses of his students in three "Stages" (Inhelder and Piaget, 1958, pp.125 - 132):

Stage I. Absence of the operations necessary for an objective account of the experiment and the use of contradictory explanations and corrections after the experiment.

Substage II-A. Attempts to eliminate contradictions and corrections after the experiment.

Substage II-B. The beginning of the reversal of the problem in the direction of slowing down.

Substage III-A. Explicit reversal of the problem of motion during the experiment.

Substage III-B. Conservation of motion.

Inhelder and Piaget (1958)

Briefly, the transition between Stage II and Stage III occurs when, in deciding how far the ball goes, the student alters his attention from considering the question: "Why does it go?" to answering "Why does it stop?" These two

categories conveniently describe the replies of the students in the present work. All of the students gave objective accounts so none could be placed in Stage I.

Table 8 gives the total percentage of students who were assessed in these stages on Task 1a and Task 1b and also on the task as a whole. Results are also given by sex. If a student demonstrated conservation of motion on one part he was assessed as though he demonstrated conservation of motion on the whole task.

It can be seen that boys tended to dominate the upper levels of Stage II and Stage III and girls fell mostly in the lower levels. If the Stages are taken as a whole, the results are very similar for both sexes: Slightly more than half boys and girls were placed in Stage II and a little less than half boys and girls in Stage III.

It can also be seen from Table 8 that students tended to do better on Task 1a. As explained before in Chapter 4, this is probably due to the nature of the task; in Task 1b the relative masses of the balls is a complicating factor both in initiating motion and in its cessation. Frictional forces appear to the students to be of less importance in Task 1b than in Task 1a. Thirty students were consistent in the type of reply they gave to the two parts of Task 1. But for seven students there was a considerable difference in their replies. For example, Anne said in the first part of the first task with one ball:

Table 8

Distribution of cognitive levels in tasks

Cognitive stage	Percentage responding							
	Task 1a	Task 1b	Task 1	Task 2 Inertia	Task 2 Ref. mot	Task 3	Task 4	Task 4
<b>Girls</b>								
Stage IIA	57.1	78.6	50.0	14.3	(37.5)		33.3	
Stage IIB	7.1	7.1	7.1	42.9	( 7.1)	50.0	8.3	
Stage IIIA	14.3	7.1	28.6	28.6	(28.6)	28.6	33.3	
Stage IIIB	14.3	7.1	14.3	14.3	(28.6)	21.4	25.0	
<b>Boys</b>								
Stage IIA	30.8	46.1	26.9	7.7	(30.8)		20.8	
Stage IIB	3.8	19.2	26.9	26.9	( 7.7)	38.5	4.2	
Stage IIIA	19.2	26.9	11.5	26.9	(11.5)	26.9	50.0	
Stage IIIB	38.5	7.7	34.6	38.5	(50.0)	34.6	25.0	
<b>Total</b>								
Stage IIA	40.0	57.5	35.0	10.0	(32.5)		25.0	
Stage IIB	5.0	15.0	20.0	32.5	( 7.5)	42.5	5.6	
Stage IIIA	17.5	20.0	17.5	27.5	(17.5)	27.5	44.4	
Stage IIIB	30.0	7.5	27.5	30.0	(42.5)	30.0	25.0	



A. *This metal thing (the groove) is causing friction to act on the ball, slowing it down.*

I. *If there wasn't any friction?*

A. *It would keep on going.*

In the second part of Task 1 when asked whether there would be any difference if the glass marble and the heavier ball were used she said:

A. *There shouldn't be except maybe the bigger one will not go as far and the marble will go further.*

I. *Why?*

A. *Cause they weigh less?*

I. *The marble weighs less, what difference does that make?*

A. *It's not as hard to get it moving if there isn't as much weight to get moving, it's easier to move. And the bigger one is harder because it weighs more than the other one.*

In Task 1a, Anne conserved motion noticing that frictional forces slow down the ball (substage IIIB); in Task 1b, she made no mention of friction stating that weight is the determining factor in the motion (substage IIA). This illustrates that not only do different individuals pay attention to different facets of a situation but that there is variation within one person to the aspects to which he pays attention even in similar situations.

Greg is another student whose reply would be classified in Stage IIA. For these students, the motion could be described as:

$$\text{Force} = \text{mass} \times \text{distance}$$

When the ball stopped close to the place which the student had predicted, Greg was asked to explain why the ball behaved so:

G. *Because of the impact force that is given off by the spring and the board which will drive it down to a certain point at which it loses its velocity and stops.*

I. *Why does it lose its velocity?*

G. *Because there's nothing pushing it. At the beginning there, it's that spring and the piece of wood there that drive it forward and as its speed - as its velocity- its velocity will decrease because there's nothing else that's pushing it.*

I. *Does it need something to push it to keep it going?*

G. *Yes.*

I. *Why?*

G. *It needs something so that it will keep a constant speed because an object can't keep up its own speed like a ball because it's got*

*nothing to keep it up at the constant speed.*

In sub-stage IIB, resistance is beginning to be of importance. For example, when asked to explain, Lawrence said:

L. *Because there's no force pushing it but the sudden force just pushed it. Like this thing, if you were to pull it and let it go it would roll for a ways and then stop because the force is still on it.*

I. *So that's why it stopped. Is there any way I could get it to go further?*

L. *Pull that thing further back.*

I. *Without doing that.*

L. *You could grease this or get a smaller ball.*

I. *If I greased it, it would go further? What difference does the grease make?*

L. *It lubricates it.*

I. *Why does it go further when you lubricate it?*

L. *It makes it more slippery.*

I. *What is happening that is different when lubricating it?*

L. *Well the ball's touching both the sides. The ball is bigger than this little groove there. I guess the sides are making it slow itself down and if you lubricate it I think it would go*

*faster because it would slide through there more.*

- I. If you got rid of the effect of the sides on the ball, how far would it go then?

*L. It would probably go just about to the end.*

Lawrence does not consider that resistance is of great importance in the movement of the ball. For him, there is a self-expending force causing motion which will halt the marble before the end of the track.

The influence of resistance increases with maturity until it is the major factor in the movement of the balls. Sub-stage IIIA would include those students who, while giving resistance the major role in the slowing down process, thought the ball would stop eventually anyway. An example of this sub-stage is given by Brian:

*B. The ball will come this way and start slowing down as it loses momentum.*

I. Why?

*B. Maybe friction against the sides.*

I. If there was no friction, what would happen?

*B. It would just keep going.*

I. And never stop?

*B. Oh yes, it'll stop.*

A few students possessed conservation of motion and focussed on the retarding forces which acted on the balls. For these students who were in Stage IIIB,

Energy from spring = kinetic energy + work done against  
resistance

For example, Carman had this type of reply

C. *It'll start off at the speed the spring travels  
- well a split second and it'll be travelling at  
that speed and gradually it will slow down.*

I. Why?

C. *Friction and the air will cause it to slow down.*

I. Friction and the air?

C. *Friction caused by the air and the rail.*

I. If there wasn't any friction, what would it do?

C. *Out in space you need no power to keep at a  
constant speed because it's a vacuum: there's no  
friction.*

## Task 2. Inertia of a Ball in a Cart

For a full understanding of this task, the interpreter must see the motion of the ball relative to external frames of reference. When the cart is first pulled, the ball remains stationary to an external frame of reference. Then, when the back of the cart hits the ball, the ball moves forward with the cart and continues its motion forward when the cart stops. The observer must also understand the inertial forces which hold the ball still at first when the cart moves forward and then keep it in motion when the cart stops.

Piaget and his assistants also performed similar experiments to this one but with younger students. (Piaget, 1973). Piaget presented a series of five tasks on inertia of increasing complexity. The fifth and final task was a ball in the centre of a cart as is Task 2 in this study. Piaget defined the cognitive stages by the child's success on the tasks. In Task 1, the child was placed on an experimenter's shoulders and the mat pulled underneath them. In question 2, the child was replaced by a doll and the mat by a piece of paper. In question 3, the doll was placed in a cart and in question 4, a ball was placed at the back of a cart and the child asked for predictions and explanations when the cart was moved. The cognitive stage was determined by the correct predictions which the child made and on his degree of understanding. (Piaget, 1973, *La formation de la notion de force*, p.168).

An attempt was made to use the same criteria in assigning cognitive stages in this study. Some modifications were necessary because the previous questions had not been set. The criteria were:

Substage IIA, the student did not predict correctly nor have any apparent intuition of relative velocities or of inertia.

Sub-stage IIB, the student predicted correctly but had no more idea of relative velocity or of inertia.

Sub-stage IIIA, the student predicted incorrectly but had some perception of relative velocities and a partial

understanding of inertia.

Sub-stage IIIB, was similar to Stage IIIA but the student predicted correctly.

The distribution of stages amongst the genders and in the sample as a whole is presented in Table 8, (p 121). Again, the boys seem to perform better on this task than do the girls. An analysis of the protocols tends to suggest that girls generally have more difficulty in perceiving the relative motion of the ball and cart. Barb for example, had difficulty with her explanation:

B. *Well, you pulled it and you set it in motion, you set the wagon in motion but the ball in the wagon wasn't in motion so it had to compensate for that by moving the other way.*

I. *I see what you mean. The wagon moved, what happened to the ball?*

B. *It stayed where it was but it couldn't because you pulled it, forced it the other way.*

On the other hand, there was a tendency for the boys to have less problem with the relative motion but to have difficulty in perceiving the inertia. Wayne gave an example of this:

W. *When it starts, the ball will roll to the back of the cart and when it stops it will roll to the front.*

I. *Why?*

W. *Since the ball isn't attached to anything.*

*Probably because the atmosphere surrounding the*

*ball will hold it in place and prevent it from moving with the cart.*

While Wayne could see that the ball was held in place and did not move with the cart, he explained the inertia of the ball by the atmosphere. This appears to be a very primitive idea.

Not all the girls found difficulty with this task.

Wendy was an exception:

*W. When you pull it, the ball will move back because it's remaining in the same place, it's not being pushed so it's staying in the same spot consequently as this moves this will appear to move back and when it stops it's going to move forward because once it hits the side it's been given pressure to push it so it's going at the same speed as the cart so when you stop the cart, the ball still has that motion so it's going to continue forward.*

Considering all thirty eight students whose interviews are studied in this task, three of the thirteen girls perceived the relative motion when the cart first moved and seventeen of the twenty-five boys. This gives a chi-square of 6.92 which is significant at the 0.01 level. Using Yates correction for small expected frequencies, (the smallest is 6.8) chi-square is 5.23 which is significant at the 0.05 level.



These results which suggest girls have more problem with perception than boys are similar to those obtained by Witkin and others with field dependence/independence and with embedded figure tests. (Witkin et al., 1962) This can be a problem for girls in understanding physical concepts particularly when the ball in the cart is used as a demonstration for inertia.

### Task 3. Inertia in Space

This task was sufficiently similar to Task 1 to assign cognitive levels on the same basis, that is, the extent to which the student conserves motion.

The distribution of cognitive stages in this task is again shown in Table 8, (p.121).

The levels would be assigned in this task on the following criteria:

Sub-stage IIA. The spaceship stays above the equator or falls to earth or straight out into space. There is no conservation of motion.

Sub-stage IIB represents the beginning of the reversal of the problem of slowing down. This would be demonstrated by the student saying the spaceman slows down because he has no propulsion.

Sub-stage IIIA. The spaceman follows behind the spaceship but not as fast because he is lighter or he stays near to the spaceship but could not go on forever.

Sub-stage IIIB. The spaceman stays with the spaceship

because his motion is conserved.

These levels diverge from the Piagetian stages with a sharper differentiation between Substages IIA and IIB. There was a clear-cut division between those who had the spaceman lose all his motion when he let go and those who saw him continue moving for a while. It was necessary that the former students did not perceive his motion relative to external fields when he was in the spaceship. In Task 1 with the balls in the groove, levels 2 and 3 are not as sharply distinguished because of the nature of the task. A task will only demonstrate those levels of cognition which are inherent in the situation. So the assigning of specific sub-stages or sub-levels seems to depend as much on the task as on some biological or psychological state in the student.

The predictions the students made usually but not always indicated their cognitive levels. For example, Shawn compared the spaceman's situation with that of a person on the hood of a car, as reported in Chapter 4, and predicted the spaceman would stay with the spaceship. When asked about the spaceman pushing away from the spaceship in space he said:

S. *He'll drift up there, I guess.*

I. Will he go on or is he going to stop?

S. *No, he'll be kind of suspended in space.*

I. Will he stop like that or will he go on?

S. *I don't think he'll go on.*

I. Where will he go?

S. To the extent of his force after it's gone he'll kindof just float.

This is a totally non-conservationalist view-point and suggests that this student was not conserving motion in the first part of the question.

One student conserved motion with resistance predicting that, if orbiting close to earth, the spaceman would be some way behind the spaceship because of the resistance due to the density of the atmosphere. The further away from earth he was, the less atmosphere and therefore the closer to the spaceship he would be. She also thought that the spaceship had engines. It is not logical for a conserver of motion to believe that the spaceship had engines but in this case the student indicated that the engine was needed because of the resistance of the air.

#### Task 4. Acceleration Produced by a Constant Force

This task differs from the other three by not testing the students' understanding of inertia or of Newton's first law of motion. It does test their understanding of his second law of motion in asking the reason for the acceleration. It was decided to draw up cognitive levels on this basis to see how they correlated with cognitive levels based on understanding of inertia.

To assign cognitive levels on the understanding of the second law a decision was made to base it on the understanding of the cause of the acceleration. The

following criteria were used to assess levels.

Stage 1. An inventive force such as the wind is used to explain the increase in speed. No students in this study seriously believed that a wind could cause the acceleration.

Sub-stage IIA. A one to one relationship between force and speed. Students in this stage explained the increase in speed of the cart by an increase in the force of gravity acting on the falling weight.

Sub-stage IIB. The movement of the cart is analogous to that of a falling body. Students in this stage knew that a falling body increases in speed which is not a concept easily acquired in everyday life from observation. For this reason and because of the uneven distribution in time as described in the previous chapter, it was believed this represented learning rather than a cognitive stage.

Stage III. The concept of increasing momentum or speed with a constant applied force or the energy increases with continued application of the force. The third stage requires a much more abstract cognition than any of the others similar to the acquisition of inertia.

The distribution of these levels is given in Table 8 (see p.121).

### B. Consistency in Cognitive Stages across Tasks.

A Pearson product-moment correlation was run across the cognitive stages assigned in the first three tasks. The results are presented in Table 9.<sup>a)</sup>

The results of the correlations appear to demonstrate a consistency across the tasks though not very great. The strongest agreement appears to be between Task 1, the balls in the groove and Task 2, the ball in the cart. The correlation is significant at the .05 level.

In this type of study there are many factors which effect these figures and the relative contributions of these factors are difficult to determine. During the interviews sensitive students may have gained insight into some problems from subtle clues unconsciously acquired from the interviewer. The point at which closure to a problem was applied was not tightly controlled although it was usually when the best response from the student seemed to have been obtained. Although the initial questions were standardised, the following questions were more flexible because of the desire to explore the student preconceptions freely. Assigning cognitive stages on the criteria described earlier in this chapter is not a straight-forward operation. For example, the importance ascribed in Task 2 to the perception

<sup>a)</sup> For all correlations the same data file was used. Only thirty six student records were complete so only this number was used in the following correlations. The reasons for the loss are as follows: One student dropped the course before the end of term. One student missed the criterion test and the test of another student was lost. As reported before, the tape of one task on a student interview was lost.

Table 9

Correlations between sex, cognitive stages and achievement in physics

	Sex	Task 1	Task 2	Task 3	End of term	Criterion test
Task 1	0.22					
Inertia	0.12	0.37*				
Task 2	0.09	0.48**	0.70***			
Rel.mot.	0.28	0.33	0.34*	0.55***		
Task 3	0.34*	0.26	0.12	0.26	0.03	
End of Term	0.18	0.43**	0.10	0.43**	0.49**	0.52***
Criterion Test	0.13	0.13	0.16	0.12	0.10	0.12
Task 4						

\*0.05 &gt; p &gt; 0.01

\*\*0.01 &gt; p &gt; 0.001

\*\*\* p &lt; 0.001

of relative motion can strongly effect the distribution of cognitive stages particularly between stages.

In spite of these complicating factors there does appear to be similarity in the manner in which students reply to tasks. Considering the difference of some student responses to Task 1 (as reported early in this chapter), a high correlation would be suspect.

There was a consistency in the perception of motion relative to external frames of reference in Tasks 2 and 3. Ten students used a force in Task 2 to explain the movement forward of the ball when the cart stopped. On Task 3, eight of these students expected that the spaceman would not have horizontal velocity and would remain over the equator. Shawn, as already described drew an analogy with a person on the hood of a car and said he would stay with the ship. Marsha also predicted he would be with the ship but she had just completed Task 2 where finally she had perceived relative motion. Both of these students said that when the spaceman pushed himself off in space he would only go to the extent of his push.

Eight of these ten students scored below the mean on the criterion test and on end of term marks. Shawn scored above the mean for both while Gail was above the mean on the criterion test and Karen above the mean on end of term marks. Comparing these students in their performance in the test, one half of them were successful in question 7 compared with sixteen of the twenty seven other students

which is very similar. They performed worse than the others on questions 11 and 12 though not significantly. Three of these students conserved motion on question 11 while eighteen of the remaining twenty seven did. Two of these students scored more than half marks on question 12 while twelve of the other twenty seven did.

### C. Student Preconceptions Related to Achievement

#### Criterion Test Achievement

The students' performance on the criterion test was significantly related to one preconception on each task. In Task 1, the initial explanation the student gave for the movement of a single ball was positively correlated to achievement on the criterion test, ( $r = 0.44$ ,  $p < 0.01$ ), (see Table 9, p.135). That is, the more sophisticated the reply to this first task, the better the student tended to perform on the criterion test. In Task 2, those students who gave as an explanation for the movement of the ball in the cart some reaction or force, were negatively correlated with achievement on the criterion test. The value of this correlation was  $r = -0.43$ , ( $p = 0.01$ ). In Task 3, the possible positions for the spaceman were numbered, those nearest the spaceship having the highest score. The initial responses of the students were related to performance on the criterion test, ( $r = 0.40$ ). The probability for this occurring by chance is less than 0.02. In Task 4, the explanation that the cart gains momentum or speed from the constant applied



force was less strongly related to achievement, ( $r = 0.37$ ,  $p < 0.05$ ). It seems that those students who have the more mature preconceptions are able to do better on this type of test. It may be that these preconceptions do not reflect some innate characteristic but in many cases are acquired. In these cases interest and experience could cause relationships such as those reported.

#### **Achievement on End of Term Marks**

On all the preconceptions tested for relationship with other factors there seemed to be no significant correlations with the end of term marks, (see Table 9, p.135). There may be some preconceptions which were omitted that would show a significant relation.

#### **Relationship between Achievement Marks**

There was a positive correlation between scores on the criterion test and end of term marks ( $r = 0.55$ ,  $p = 0.001$ , see Table 9, p.135). At one school, from which there were five students, the criterion test was used as an end of section test and therefore would contribute to end of term marks. At the other schools the criterion test was stressed beforehand as an important test but was not included in the end of term mark. It should be remembered that the end of term mark reflected performance on other sections of Physics 10 than the narrow field of Newton's first two laws reflected in the criterion test. This is possibly one reason why there is no significant relationship between end of term marks and preconceptions.

#### D. Cognitive Stage Related to Achievement

##### Criterion Test

The criterion test was related to the cognitive stages assigned in Task 1 and Task 3. The correlations were respectively,  $r = 0.43$ ,  $p = 0.010$ , and  $r = 0.49$ ,  $p < 0.01$  (see Table 9). An earlier assessment of cognitive stages in Task 2 gave greater weight to the perception of relative motion. These assessed stages were also related to the criterion test, ( $r = 0.43$ ,  $p < 0.01$ ).

##### End of Term Marks

End of term marks were not significantly related to any assigned cognitive stages. As suggested above this may reflect a broader base of subject matter or that end of term marks do not test cognitive stage.

#### E. Variables Influencing Preconceptions

##### Historical Antecedents

Many of the preconceptions demonstrated in the students' responses resemble beliefs of ancient philosophers especially those of Aristotle. Several students imagined that the air was a factor in sustaining motion by "turbulence" - swirling over the object to push it from the other side. There is no way to ascertain whether they were in any way influenced by diagrams in the Physics text book. If they were, they had not read the captions with care. There was also a tendency to feel that gravity acted with a greater effect on a heavy body than on a light one. This too was a

Greek belief in the case of falling bodies. Without checking experimentally the Greek philosophers stated that heavy bodies always fell faster than light ones. Several students described motion as if the body lost energy or momentum as it moved, that is, as if motion was self-expending. This was an idea introduced by Philoponus in the fifth and early sixth centuries A.D. That the beliefs of ancient philosophers should be reflected in the student of today should not cause surprise for the Greek philosophy explained everyday phenomena with common sense ideas. Science does not do this. Physics teaches about a seemingly unreal world outside of the experience of students.

#### **Space Travel, Science Fiction and Previous Teaching**

Modern science does have an influence on the preconceptions of students particularly, of course in relation to problems in space. However, the conceptions acquired from space travel sometimes distort the alternative framework away from the generally accepted structure of knowledge. The term weightlessness applied to the spaceman is misleading. Students sometimes reluctantly assume that gravity acts on the spaceship but not on the spaceman. At other times they assume that there is no gravitational field and then must invent an agent to hold the spaceship in orbit - an engine in the spaceship or even just that the earth turns underneath. Science fiction plays its part. If a spaceman leaving a moving spaceship in a film just floats away then conservation of motion is not reinforced in the student's

mind. But might it not be that a student who does not conserve motion does not see the spaceman still moving when he leaves the spaceship?

Some students demonstrated a remarkable sophistication with regard to their conceptions. In many cases interest was a major factor though the reverse was not always true: not all the students who professed interest in science possessed mature conceptions. Some influence due to teaching was evidenced. Many students had learned from teaching on inertia in the case of the ball and cart though sometimes inability to perceive relative motion interfered with learning.

Most students had learned that gravity was a force pulling downwards but this did not prevent them accrediting it with slowing down horizontal motion and in maintaining it as in situations of inertia of a moving object.

#### Gender influences

There was a significant tendency for girls to do better on end of term marks than for boys, ( $p < 0.05$ ). Further analysis indicates that the correlation between end of term marks and on the criterion test is gender linked. For boys the correlation is highly significant, ( $r = 0.73$ ,  $p < 0.001$ ) whereas for girls there is no significant relationship, ( $r = 0.35$ ,  $p > 0.05$ ). This suggests that while girls are diligent and work hard on term marks, they are not as able to tackle the type of question set on the test as are the boys.

There was less agreement also between the performance of girls on the tasks and their achievement on the criterion

test than there was for boys. This is probably due to the preponderance of primitive replies in the girls' answers to the tasks which is probably due to their lack of experience in the world of physics.

## Chapter VI

### SUMMARY DISCUSSION AND IMPLICATIONS

#### A. Summary

##### The Problem

Students beginning the study of physics often find inexplicable problems in learning certain parts of the subject. Often, despite great effort on the part of the student and teacher, concepts become even more confused and at variance with everyday life even as the terms become more familiar. It has been suggested (Driver and Easley, 1978), that one explanation could be that students have already acquired preconceptions about their surroundings which are subtly different from the accepted scientific concepts which the teacher presents. These preconceptions are all the more difficult to confront because they are unsuspected. Furthermore, even for those students who achieve a measure of success in the subject, it is possible for earlier preconceptions to appear and cause confusion.

One area which is particularly susceptible to interference in this way is that of dynamics and especially the subject of Newton's First Law of Motion which states that a body continues in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by external impressed force. This is contrary to every-day experience where all motion is opposed by resistance and

requires a force to sustain it. Thus inertia of a moving body is not easily perceived' as such and it may be that the concept is seldom, if ever acquired intuitively.

To support the belief that students might not be able to perceive the inertia of a moving body merely from their own first hand experience, we can examine historical records of early philosophers to observe that many centuries of civilisation had passed before the concept of inertia became established (Franklin, 1978). Before Galileo, scientific thought was dominated by the teaching of the Greek philosophers such as Aristotle whose physics was subordinated to philosophy and religion. (Randall, 1962).

The purpose of the present study was to investigate the preconceptions of Physics 10 students before they began study of Newton's laws of motion. The intention was to determine the nature and extent of their preconceptions in the field of inertia and to discover any relationship between preconceptions held and performance in physics as determined by end of term marks and by achievement on a criterion test. Another purpose was to discover any gender differences in the type of preconception held or the extent of these preconceptions. Comparisons were also made between the students' ideas and those of early philosophers. Modifications due to exposure to space travel, science fiction as well as classroom instruction were also sought.

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' Although the motion of the planets may be observed, it is seldom noticed as continuous movement

## Procedures

The study was conducted in four randomly selected Senior High Schools in the Edmonton Public School system. Five students were randomly selected from each of eight classes also selected randomly from these schools. The students, twenty six boys and fourteen girls were each interviewed individually for an average of half an hour and were presented with four tasks for which they were asked to predict and explain events. The interviews were tape-recorded and later transcribed and analysed for the concepts expressed.

The first task was to explain the motion of a steel marble along a groove after impact from a spring. This was followed, as part of the same task, by a request to predict which of three marbles of differing size and mass would travel furthest along the groove and to explain this prediction and the subsequent events when the marbles were projected in turn along the groove.

In the second task, the student was asked to predict and explain events when a ball was placed in the middle of a cart and the cart was sharply pulled and then stopped.

The third task was presented as a spaceship and spaceman orbiting the earth. The students were asked to predict and explain the fate of the spaceman if he were to let go of the spaceship. They were also asked to describe events if he pushed himself away from the spaceship in outer space.



The fourth task was slightly different. It presented accelerated motion in the form of a cart pulled by a string over a pulley which was attached to a falling weight. The students were again asked to predict and explain events and any changes which might occur if the string was made long enough that the weight would hit the floor before the cart reached the pulley. This task, which involves Newton's Second Law of Motion, was included to determine whether there was any relationship between the students' understanding of Newton's First Law of Motion and of his Second.

### **Major Findings**

#### **Nature of preconceptions**

Student ideas in the present sample were found to range from comparatively primitive conceptions to the sophisticated concept of conservation of motion. The primitive conceptions expressed such ideas as that all motion requires force for its continuation or that the power of motion is self-expending. Sometimes cessation of a real or imagined force is seen as an initiator of motion in the opposite direction from that of the force. With increase in maturity of thought, resisting forces such as 'gravity', friction and air resistance are mentioned. Concurrent with these ideas the concept of conservation of motion may or may not be demonstrated. Its absence from an explanation need not indicate that the student does not possess the concept.

When a student's reply included more than one idea, the first, the intuitive one was usually the least mature.

Seldom was a response preceded by one which could be called more sophisticated. The nature of the preconceptions expressed by the students depends to some extent on the task. Conservation of motion does not always appear as an appropriate concept in some situations.

In the first task, which studied the horizontal motion of marbles in a groove, almost all the students gave a primitive response at first. About one third of the students did not or could not modify this reply, while more than one third of the remainder of the students were able to respond with the sophisticated concept of resistance. Similar distributions of primitive and sophisticated replies were obtained in the other tasks except that some greater success was achieved in Task 2 in all respects.

#### Consistency across tasks

There seemed to be consistency in the students' replies across Tasks 1, 2, and 3, most particularly with the higher level responses: Those that replied in a scientific manner to one task would be most likely to reply in this manner to another. There was no agreement between the degree of sophistication attained by the students in either of the first three tasks and the way they replied to Task 4 when the degree of sophistication was decided by the criteria used in this study. If perception of relative motion was the criterion of success on Task 2 there was strong agreement between success on this task and on Task 3 ( $P < 0.001$ ) and between Task 2 and Task 1 ( $p < 0.01$ ; Table 9, p.135). If

perception of inertia was the criterion of success then the agreement between Task 2 and both Task 1 and Task 3 is less ( $p < 0.05$ ).

There was apparently a little consistency in the use of gravity or weight as an agent which sustained horizontal motion or opposed it. More than half of the students used it in this manner at some time in the first three tasks; six of these students were consistent users and applied the concept on more than one occasion.

#### **Relationship to achievement**

The criterion test was related to the conceptual levels assigned on Tasks 1 and 3 and on Task 2 if perception of relative motion was the standard of success, ( $p < 0.01$ ). The end of term marks did not seem to be related to any assigned conceptual level but was correlated with the criterion test ( $r = 0.52$ ,  $p = 0.001$ ). This relationship was sex-dependent. For boys the correlation between criterion test and end of term marks was much greater than for girls. For boys,  $r = 0.73$  ( $p < 0.001$ ), for girls,  $r = 0.44$ , ( $p = 0.160$ ). This means that the relationship between the two sets of marks is not significant for girls.

#### **Resemblances to early philosophic thought**

Many preconceptions discovered in this study resembled beliefs of early philosophers and scientists. Some students appeared to believe that continuous motion requires a force to sustain it which is similar to Aristotle's (384-322 BC) teaching about violent motion (that is, not natural motion).

(Randall, 1962).

Another Aristotelian conception not as widely held is that the atmosphere plays a part in sustaining motion. One or two students imagined that the air swirling around a cart caused it to move or, increased its speed. A few more used the atmosphere to explain why the ball appeared to move to the back of the cart when the cart was initially moved and explained the apparently sudden move forward by the absence of the pressure of the air.

Aristotle also taught that the effect of gravity was greater on a larger body than a smaller and that a heavy body will always fall faster than a lighter one. A similar thought was evidenced by those students who imagined that gravity would pull the heavier spaceship faster around the earth than the spaceman. Students also showed willingness to believe that different laws of motion applied in space from those on earth; another conception taught by Aristotle.

Philoponus (late 5th century and early sixth) questioned Aristotle's ideas. He believed that a medium was not necessary to sustain motion and that motion was self-expending (Franklin, 1978) an idea which some students seemed to believe. Shawn for example, when he was asked how the energy in the rolling ball was used up said: "It was applied in getting from there to there and it was used."

Students who did not believe that the ball shared the motion of the cart or the spaceman that of the spaceship were reflecting an argument of Buridan's (1300-1358 AD)

against the hypothesis of the rotation of the earth. He believed that if the earth rotated, an arrow shot vertically upwards would not fall back in the same place because it would not share the rotation of the earth. This was actually contradictory to his "impetus" theory which regarded "impetus" as something permanent unless acted upon by resistances or other forces. It may have been that he was considering all possible ideas or there may have been religious reasons for his inconsistency.

#### **Influence of modern science science fiction and previous instruction**

It might be expected that students would have been influenced by space travel and science fiction. Some students seemed to have acquired a knowledge of conservation of motion from space travel. When discussing the motion of the single ball they mentioned the fact that without resistance it would go on forever, as in space.

While some students were conversant with the factors involved in earth orbits, others had acquired incomplete knowledge of the system and on assimilating this with pre-conceptions already possessed produced some distinctly personal alternative frameworks of knowledge to explain and predict events in space.

One particularly confusing concept was that of weightlessness. Although occasionally a student would describe the spaceship "falling" in its orbit around the earth it is hardly surprising that there were very few expressing this.

concept since it involves knowledge and understanding of circular motion and centripetal force. Many students had heard of the "weightlessness" of an astronaut however, but not the accompanying "weightlessness" of the spaceship. When asked to express their ideas in this study, they had difficulty in accommodating the conception. They resorted to several solutions such as that gravity did not act on the spaceman but did on the spaceship or that the orbit was too far from the earth for any gravitational field at all. The spaceship revolved around the earth because it had motors or rockets or was otherwise powered and directed.

Orbits were seen by some students as something almost tangible around the earth. The conceptions varied from an almost concrete but invisible factor to something related to speed, that is almost the scientific concept of orbits. Other students thought that other forces kept the spaceship above the earth - the gravitational field of the sun or the moon or the spaceship's own weight. Some students explained orbits by holding the spaceship still while the earth rotated beneath it.

Some students did not consider that the spaceman was moving when he was in the spaceship so when he left it he was stationary. Even if the same student perceived that the ball in the cart maintained its motion when the cart stopped, there was sometimes no transfer of this inertia to the region of space. This conception was reinforced by space shows; several students mentioned that the spaceman is seen

'floating' away.) In fact, 'floating' was most often used to describe his fate.

#### Gender differences

Sex differences were significant in some areas. Girls were more likely to offer primitive explanations for the tasks than were boys but although there was a corresponding tendency for boys to produce more advanced ideas, this difference was not significant. Girls were more likely ( $p = 0.04$ ) to do better on end of term marks than boys. The gender difference in the relationship of this end of term mark with the criterion test has already been mentioned, (p.146).

There was a greater degree of agreement for boys between the way they performed on Tasks 1, 2 and 3 and their performance on the criterion test than there was for girls.

#### Use of terms gravity and weight

Many terms such as gravity, weight, energy, force and momentum are used interchangeably in various contexts. This was not unexpected. A more surprising discovery was the use of the terms. Gravity and weight in particular seem to have very personal meanings. Although almost all students recognize them as representing a force attracting all bodies to the earth, they also can be seen as a factor acting in other directions.

In Task 1, gravity pull was described as slowing down the motion of the balls on a track, sometimes it seemed quite separate from friction. Gravity pull was also

described as something which held the balls in place and had to be overcome to get them moving; it was larger for the heavier balls.

With the ball in the cart, gravity again (or weight, here) held the ball in place when the cart moved at first. The weight, or G-force was perceived by other students as something which held the ball at the back of the cart while it was moving. Momentum, gravity and weight were all described as something inherent in the ball which thrust forward when the cart stopped. Seemingly different was the description of gravity pulling down and thus pulling the ball forward.

Gravity was perceived as playing a major part in Task 3. Gravity pulled the spaceships down so, if the spaceman is weightless, he doesn't move when he leaves the spaceship. Or, if the gravitational field is acknowledged as acting on the spaceman, the force is less on the smaller mass, therefore, he goes slower. Gravity may pull towards the earth but because it is small, some students thought, the spaceman would not be pulled down to earth.

The explanation of acceleration of a falling body being due to increased force of gravity nearer the ground in Task 4, is reflected in work by Aguirre where younger children thought a weight would 'be heavier' closer to the ground (Aguirre, 1978). Champagne, Klopfer, Solomon and Cahn (1980) had similar results. Inspection of the vocabulary of Aguirre's students suggests though that these are different



conceptions. Whereas Aguirre's students appear to have a primitive conception of 'heavier' near the ground the older students in this study seemed to be arguing that the force of gravity gets larger on approach to the earth and that this increase is sufficient to explain the increase in speed. This idea that a ~~constant~~ force is needed to increase speed is a corollary to the conception that all motion needs a force to sustain it and the idea is therefore still a relatively primitive preconception.

#### B. Discussion

It seems that, regardless of the more sophisticated ideas which students may possess about a familiar situation, their first reaction can be similar to that of earlier philosophers. Although few of them said that motion needs a constant force as Aristotle taught, most of them seemed to believe that the attribute causing motion was used up. For some students, this was later changed to energy which was lost because of resisting forces but a large number believed that motion was self-expending and even some of those knowing of resisting forces thought that in any case without resistance, the motion would dissipate.

The preponderance of primitive responses in the initial replies of the students to the tasks is not surprising. These are the intuitive ideas which result from early interaction with the environment. The ideas which have been consciously acquired follow later. In fact some of the

primitive ideas are not in themselves contradictory to accepted scientific explanations: On earth, the energy of a moving body is used up (in transforming kinetic to heat energy). To make this complete one must qualify it with: 'The energy is used in overcoming resistance'. Some of these primitive explanations give a much more commonsense description of the environment. This is why they reflect the ideas of early philosophers.

The more mature ideas would be more likely to have been learned from other sources than mere observation or experience. To acquire such ideas probably requires some conscious thought but not necessarily overt instruction or learning. This would be affected by factors such as interest, availability of information as well as cognitive ability and it would be effected by interaction between these.

The use of the terms "pull of gravity" and "weight" are an example of the persistence of intuitive ideas. The learned concept is that gravity is a force of attraction to earth but the intuitive ideas of inertia and friction which come from physical experience are combined with this knowledge. So this force, known to act vertically, is used to describe a power holding things in place as when the cart moves in Task 2 and Task 1; it slows down horizontal motion in Task 1; and continues horizontal motion or even initiates it in Task 2 when the cart stops and in Task 3.

Perhaps the idea of gravity as a slowing-down agent should not be too surprising. Friction is not an experienced force to an observer; the weight is more tangible. If the student does not find conflict in the idea of linear motion being affected by forces at right angles to its direction, then gravity can be a more obvious agent for retardation as in the task with the balls in the groove and with the cart being pulled by the falling weight than a horizontal force which is not very obvious. Some students thought that it was the force of gravity acting on the cart which had to be overcome before the cart would move. When an object is only seen relative to its immediate surroundings as with the ball in the cart and the spaceman in orbit, then the vertical force of gravity is one of the forces suggested which causes the ball or spaceman to thrust forward.

There seems to be some real difference between the sexes in giving primitive responses on Tasks 1 and 3. Girls were significantly more likely to give such replies at the beginning of Physics 10 yet achieved better on end of term marks probably because they were more diligent in their studies. A noticeable result was that though there was a significantly greater use of primitive conceptions by the girls, the greater use of sophisticated concepts by the boys was not significant. It suggests that girls begin at a disadvantage but are more likely to be flexible. One reason for the girls' early disadvantage is no doubt due to their lack of experience in the area because of inclination and

social factors. This could lead also to less adequate understanding of vocabulary. For example, when asked what friction was, Anne said, "Different forces acting". Although she had used the term apparently with understanding as a factor slowing down the motion of the spaceship, she did not use it elsewhere and it is possible that she did not really understand the term. Another aspect of sexual differences is that because of their lack of experience in the field, girls might benefit from more concrete experiences in classroom instruction. The purpose would not be to make the subject less formal but to give more practical work in the initial stages.

Whether there is any biological reason for girls' poorer performance in science than boys' seems to be elusive to investigation. It appears that the cerebral hemispheres have specialised functions and that this specialization takes place earlier in girls than boys. One suggestion (Sutherland, 1981) is that later development in boys allows for greater balance of functions of the two hemispheres and greater development of the activities controlled by the right hemisphere. Hence boys have greater spatial ability and girls better language development. On the other hand, Epstein (1978) suggests that growth spurts in brain development are related to the appearance of Piaget's cognitive stages. He also states that these growth spurts at age eleven are greater for girls than boys and that at fifteen is greater for boys than girls. Epstein argues that

curricula designed for boys are inadequate for girls and that girls need the stimulation of higher level reasoning at age eleven. If this is not provided then it becomes difficult to develop the faculty. The same need might be applied to some boys too.

The degree of sophistication in the student replies must reflect interest and experience. But not only these factors are important, some students professing interest were assigned fairly low cognitive levels. The interaction of interest, experience and ability would explain the consistency of assigned cognitive levels across Tasks 1, 2 and 3. It would also explain achievement on the criterion test but not the lack of agreement of assigned cognitive levels and achievement as demonstrated by scores on end of term marks. This could be explained by the broader base of end of term marks although Newton's laws of motion are a large part of the core curriculum in Physics 10. Since end of term marks were correlated with certain questions on the criterion test, ( $r = 0.6$ ,  $p < 0.001$  for questions 2 and 4,  $r = 0.4$ ,  $p < 0.02$  on questions 5 and 11), it is possible end of term marks are strongly biased in favour of recall or straight application of formulae and do not reflect ability to transfer learned concepts.

The lack of agreement between the cognitive levels assigned on the other three tasks and the level assigned in Task 4 could have been due to the criteria used to assign this cognitive level. In a similar task, Piaget used

recognition of acceleration as the criterion but only one of these students failed to see the acceleration. It could also be the manner in which these criteria were applied.

The cognitive stages in Task 2 were assigned from two points of view. One was on the degree to which the students appeared to perceive the inertia of the ball and the other was the perception of the movement of the ball relative to external frames of reference. As might be expected, the agreement between the two is fairly high,  $r = 0.7$  (see Table 9, p.135), no higher because one does not depend always on the other. It may be seen that perception of relative motion seems to correlate more highly with performance on Tasks 1 and 3 and with the criterion test. It seems that perception of relative motion might be related to some general ability. From the interviews it seems that in some students there is a great resistance to the perception of the motion of the ball relative to external references.

While it is difficult to determine to what extent conservation of motion is a learned concept, it is possible that it might be acquired by interaction with the environment in these days of space research without learning at school. The Greeks influenced philosophical thought for many centuries and this may have been why conservation of motion was so late in being accepted. Aristotle was very highly respected for centuries but language may have been a great barrier for him. The Greek language which he used did not have a term for the active verb 'moves' only for the passive

form 'is mov~~ed~~. This would pose problems in thinking of movement which does not have a continuous stimulus (Randall, 1962).

It seems from this study that both conservation of motion and the perception of motion relative to external frames of reference, have some relationship to success on the criterion test. This does not necessarily imply that they are essential to success on this test. It is more likely that all three are related to a general ability. Whether this general ability is described by "stages" or by a continuous scale is not important here.

If "cognitive stages" are real though difficult to determine and are dependent on innate structures as well as on interaction with the environment, then only the latter factor can be effected by teaching. The lack of formal structures prohibits acquisition of formal thought.

This study did not set out to prove the existence of cognitive stages but only used the idea as a tool in comparing performance on tasks. It did appear that the nature of the student differences might support the existence of some kind of stage. There were some students such as Carman who were very sophisticated in their understanding of the concepts. These students did well especially on the criterion test. There were other students who seemed to be variable in their performance but were able to achieve some success on the tasks and at times appeared to learn very quickly. There were on the other hand five students who were

very resistant to the idea of conservation of motion and to the perception of motion relative to external frames of reference and who performed poorly on both achievement scores. Whether one prefers to consider a continuous scale of ability to cognitive stages the difference in students is great.

The most useful results in this study were obtained when the student was asked a specific question such as "Where will the spaceman be when the spaceship is here?" To ask a student to predict and explain "What will happen?" when a ball is pushed along a track is open-ended and leaves the student uncertain about how he is expected to respond to the question. Asking for explanations of predictions or of demonstrated events is also open-ended but the investigator's expectation is more clear.

### C. Implications for Teaching

Students seem to enter physics classes with preconceptions many of which resemble those of early philosophers. While such ideas may obstruct learning, they may also be used by the teacher as strategies in teaching. One method is to follow the scheme of recent physics courses such as *Physics: A Human Endeavour* to follow historical philosophical thought. While that text deals with Aristotelian conceptions such as the need for constant force on a moving object, there are other conceptions of later philosophers whose ideas were reflected in the sample studied here. A



student who thinks that moving objects borrow a force which dies out even in a void would recognize the philosophy of Philoponus. Others would feel a sympathy with Buridan who decided that the earth did not rotate because an arrow shot straight up in the air came straight down. Those students would not believe that an object inside another moving object maintains that motion. Such students would learn without losing confidence.

Another possible technique is similar to Aguirre's. He suggested that students should be asked for their interpretations of the action of forces. Then from these contributions, the class can work together to formulate more scientifically acceptable concepts. The same might be accomplished with motion. The teacher could take the idea that a certain amount of force will always push a ball a certain distance. If this were true, then the surface should make no difference. But a ball given the same impulse on different surfaces will go different distances. Students would then be encouraged to consider factors which oppose the motion of the ball.

A teacher might also discern from this study that the students' use of a word does not always mean that he has acquired the concept even when he appears to use the word correctly. Many of the students showed lack of discrimination between concepts such as inertia and gravity or weight. This would probably begin to disappear as the concepts were presented and defined. Less likely to be

clearly defined are such terms as friction or force.

Empirical definition by examples might help those students who were most unfamiliar with such words.

Girls might also benefit from practical experience but not in situations where it is more profitable in acquiring marks to allow the boys to do the work while the girls make the fair copy.

The experiment with the ball in the cart to demonstrate inertia should be used with great care. Students who cannot perceive a little of the motion of the ball relative to external references, will not acquire the concept of Newton's First Law. Some perception of the ball as stationary at first is essential and the perception of a body moving when it is within a moving body is no more to be taken for granted.

The resistance some students have to acquiring the concept of conservation of motion and of relative motion and their difficulties with the subject suggest that they might perform better in a class with less formal concepts. While there are ways in which students can work individually in a class, assignment of marks appears to be a problem.

#### **D. Suggestions for Further Research**

The direction of further research is suggested by some of the findings in this study.

1. Some of the findings in this study were unexpected particularly the many connotations of the term "gravity"

and especially those pertaining to space. The ideas the students possess in this way could be explored by presenting problems in space with and without a gravitational field and comparing this with examples of inertia on earth including motion of a person in a car rounding a corner (or a ball in a cart changing direction).

2. The task with the spaceman and the spaceship dealt with the most difficult problem first, when the spaceship was in orbit. This task could be more usefully employed to test students' conservation of motion if the question of the spaceman pushing away from the spaceship is posed before the complications of the earth's orbit are involved. As a comparison either Task 1 or Task 2 could also be set. Together with this an embedded figures test could be set to test whether field dependence/independence has any bearing on the problem through perception of relative motion.
3. This study dealt with a single age group and does not indicate how the students' cognitive structures might evolve. A study of the development of these conceptions of gravity and inertia could be undertaken by testing younger children at various ages.
4. Since possession of the concepts of conservation of motion and of motion relative to external frames seem to be important in achievement in physics, some attempt might be made to determine to what extent, if any, these concepts could be taught. If success can be proved

against a control group without teaching, the result might indicate whether these concepts depend on innate structures.

5. Since responses depended to some extent on the nature of the task and how it was presented, further study should be made of student response to several modifications of a task such as presenting a simulation of a spaceman and spaceship in orbit. In order to achieve credibility with these mature students this might be best dealt with by film.

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## APPENDIX 1

## PILOT STUDY

**Experiment A. Balloon blown up and released.****Questions.**

The balloon was blown up and held closed for a while.

Q 1: "If I let go of the balloon, what will happen?"

Usually the students predicted correctly.

Q 2: "In which direction will the balloon go first?"

This was answered correctly.

Q 3: "Why does this happen?"

**Experiment B. Cart pulled by a weight over a pulley.****Questions**

Q 1: "Here is a cart, attached by a piece of string to a weight hanger with weights. I will pull the cart way back to here and let go. Can you tell me what will happen to the cart?"

By naming the apparatus of the experiment, the students were given names for the objects with which they might not be familiar. Most said that the cart will move, three said it would only do so if the weight and weight hanger were heavier than the cart.

Q 2: "Will the cart always move with the same speed between here and here?"

Q 3: "Why?"

Demonstration and again, "Why?" if the student had not predicted correctly.

**Experiment C. 2 carts pulled by weights over pulleys****Questions**

Q 1: "These are two identical carts attached as you see to weights as before. I will pull them both back to here and let go. Will their movement be the same?"

Q 2: "If I add a brick to the hanger, what difference will this make?"

Q 3: "How could I make their movement the same again?"

Q 4: "If I now remove the brick and add a weight to the hanger, what difference do you expect that to make?"

The answers were all correct and little of interest was gained from this.

**Experiment D. Marbles propelled along a metal groove.****Apparatus**

A metal groove and three small balls were produced. One ball was a small steel marble, another a glass marble of the same size and the third was a steel ball of diameter

approximately twice that of the other two.

**Questions**

"I shall place this steel ball in the groove with its side on this mark. Then I'll pull the spring back this distance so that the striker comes to other mark and then let go."

(This was to ensure as much as possible that the impact was the same for each ball.)

Q 1: "What will happen to the ball?"

Q 2: "Why?"

Demonstration. If the students' predictions were wrong, they were asked "Why?" again.

The experiment was repeated showing simultaneously the other two balls.

**Experiment E. Cart upside down and on wheels**

A small cart was presented.

**Questions**

Q 1: "I shall push this cart along the bench upside down and let go. Could you tell me what will happen?"

Q 2: "Why?"

Q 3: "Now I shall put it the right way up and do the same thing. What happens now?"

Q 4: "Why?"

**Experiment F. Action and reaction between dynamics carts with plungers**

**Apparatus**

Two carts were presented and their identical structure demonstrated. Each had a plunger but one remained inactive throughout the experiment. The two carts were placed end to end so that the loaded plunger of one was set ready to strike the other cart. Two bricks were placed with one brick behind each cart. The student was asked:

Q 1: "What will happen when the plunger is pressed?"

After his reply;

Q 2: "Where would you place the carts so that they hit the bricks at the same time?"

Q 3: "Why?"

Another brick was placed on one cart and the student asked where the carts should be placed so that they hit the bricks at the same time.

"Why?"

**Experiment G. Wagon and ball.**

**Apparatus**

A marble was placed in the centre of a small open cart which had a handle attached.

**Questions;**

Q 1: "I shall pull this wagon forward and then stop it suddenly. What do you expect to happen?"

Q 2: "Why?"

The experiment was performed. If the student had predicted wrongly, he was asked to explain "Why?" again.

#### Experiment H. Earth, spaceship and astronaut.

##### Apparatus.

A large globe, a toy spaceship and a plasticine astronaut were presented. The spaceship was demonstrated orbiting the earth with the spaceman inside.

##### Questions

This globe represents the earth and this is a spaceship in orbit around the earth. It goes like this every 36 hours (The spaceship was shown orbiting the earth in a great circle over the north and south poles). The astronaut inside needed to do repairs to the outside of the ship so he put on his space-suit and climbed out. In his haste, he forgot his life-line which attaches him to the ship.

Q 1: "If he should let go of the ship, where will he be in about 15 minutes if the spaceship has got to here?"

Q 2: "Why?"

Q 3: "If the spaceship is out in space and the astronaut climbs out again without his life-line and pushes himself off accidentally, what will happen?"

Q 4: "Why?"

Q 5: "If the spaceship is again out in space and the astronaut leaves again without his life-line and pushes himself off accidentally, what will happen?"

Q 6: "Why?"

Q 7: "How could he get back to the spaceship?"

#### Experiment I. Ball on a rotating platform

##### Apparatus

A rotating platform was presented with a small marble placed on the surface.

##### Questions:

Q 1: "I shall rotate this platform with the ball on it right here. Then the speed will be increased, it will go faster. What do you expect to happen eventually?"

Q 2: "Why?"

The problem was not satisfactory because it was difficult to set up. Because the rotation had to be accelerated, the ball always went off with a backward motion.

## APPENDIX 2

## STUDENT PROFILES

A summary of each student's replies to the tasks is given here. Student remarks are in italics, commentary is in normal print.

ALISON

## Task 1.

*It stops because it runs out of push.  
There isn't enough push behind it to push it the whole way.  
You didn't push it hard enough.  
The lighter one will go farther, the heavy one not as far.  
The lighter one doesn't need as much force.  
Friction is greater with the bigger one because of the way it sits in the groove.  
Friction makes it slow down faster.  
It wouldn't go forever with no friction because of air pressure.  
If there is no air pressure, it would go forever.*

## Task 2.

*The ball will hit the back on the start - will bounce off - hit front of cart on stop.  
Cart goes forward but ball doesn't.  
Groceries in a cart don't go forward because its not the right way for it to go.  
When the cart stops, things keep on moving to the front.  
Things in a car go the same speed as the car and don't know when the car is going to stop.  
It doesn't know cart is going to start until something hits it.*

## Task 3.

*Spaceman would follow spaceship a little bit behind or be on the spaceship.  
Too far out to go down to earth.  
Probably slower than spaceship.  
Spaceship has engines. (corrected)  
He'd go slower because he's not as big as the spaceship.  
The spaceman in space would start falling when he pushed himself off.  
He would float anywhere.  
If he started in one direction, he would just keep going.  
There would be no way for him to get back.*

## Task 4.

*Car will move if the weight is heavier than the cart.  
It will pull if the weight is the same because the cart is on wheels.  
The cart will speed up as the weight falls.  
The weight will jerk all at once when it starts*

falling and then cart will slow down.

The cart will increase its speed to a certain point and then stay at that speed.

(After seeing the weight fall)

The cart moved faster all the way.

If something falls from the sky it reaches a maximum speed but there is not enough air pressure here.

A falling body goes on increasing speed if there is no air resistance.

For a longer string, the cart will start slower, because it takes longer for the string to reach the cart.

Its like riding a bike too big for you.

The cart won't ever reach the same speed as before.

After the weight hits the floor, the cart increases its speed for a very little bit further.

Drew

Task 1

The ball rolls because its struck until friction makes it slow down.

The heavy one goes further (but changes mind immediately).

The heavy one slows down faster because of its weight.

The spring doesn't have as much effect on the larger ball.

The glass one will go the same distance as the small one. On feeling weight, no, it will go further.

Task 2.

The ball will go back on the start and forward on the stop because it is a free object.

Does gravity hold the ball standing still when the cart starts?

The ball is moving when the cart stops. The ball doesn't stop.

Task 3.

The spaceman would stay with the ship because there's no friction in space. There's nothing pulling on it.

If the thing (spaceship?) flipped over there might be a little gravity to pull something down.

The movement of the spaceship creates a force which overcomes the pull of gravity so the spaceship doesn't fall to earth.

Task 4.

The cart will move forward moving faster all the time.

It will increase its speed at  $32' / s^2$ .

After the string is lengthened, the cart will increase its speed as before but it halts sooner because the weight reaches the ground.

Then it will decelerate instead of accelerating.

Greg.

Task 1.

The ball will eventually slow down.

Air and metal friction slows it down.

The little one will go the farthest.

The little one is smaller and takes less to get it moving so it would go farther.

The larger one has more friction because it takes up more space and weighs more. The big one takes more energy to get moving faster.

Task 2.

The ball will move back in the cart on starting and forward when the cart stops. At first, the ball hasn't been pulled but the cart has. When the cart stops, the ball hasn't been stopped.

Task 3.

The spaceman will fall to earth in a ring from where he fell off.

The spaceship is falling to earth all the time when it is in orbit.

Not sure whether the spaceman would fall as fast as the spaceship (That is, whether he would lag behind). He will stay with the spaceship.

Task 4.

Task 4 was not recorded.

Gail

Task 1.

The ball is kind of heavy so it starts off real fast but it slows down because there's nothing to keep it going.

The heavier ball needs a greater shove so it doesn't go as far.

The lighter ball needs less shove so it goes faster.

It's just the weight makes it harder to push.

Task 2.

When the cart is pulled the ball will go the opposite way.

When the cart stops, the ball will roll back.

The cart slipping one way makes the ball go the other way.

The force from it (the cart?) makes the ball go.

When the cart is moving air or force holds the ball back so it rolls forward when there's nothing to hold it back.

It's the jerk of the cart stopping that makes the ball go forward.

Task 3.

The spaceman will be floating around where he got off, he's not moving.

He will float behind the spaceship or be by it for a while then he will drop behind.

The spaceship has power.

(When told the spaceship does not have power,) the spaceship will go faster because it's bigger and heavier.

If the spaceman pushes away when out in space, he will just go floating away.

**Task 4.**

The weight will fall and pull the cart if it is heavier than the cart.

The cart starts slow then speeds up.

With a longer string, the cart picks up speed until the weight hits the ground and then keeps going until the cart hits the pulley.

**Paul**

**Task 1.**

The ball goes down the track because of the energy given to it.

The ball uses up energy on moving then it stops.

The marble won't go as far as the big ball, no, that's wrong.

The heavy ball needs more energy to move a certain distance because it weighs more.

**Task 2.**

If started quickly, the ball will go to the back.

When the cart stops the ball moves to front.

The ball went to the back at first because it was not touching the cart - would that be action and reaction?

**Task 3.**

The spaceman will float around where he got off.

There's no air and no oxygen.

He's not heavy enough to be pulled by the earth's gravity. (weightlessness?)

The spaceship has its own rockets.

Away in space the spaceman would just move away from the spaceship if he pushed himself off.

He could move his arms to get back.

**Task 4.**

The cart increases speed because the gravity pulls faster and the thing (weight) falls faster.

When the string is longer, the cart will slow down after the weight reaches the ground.

It will continue moving because of the energy it has.

**Gordon.**

**Task 1.**

The distance the ball will go will depend on the power or thrust put on to it.

It will stop in a certain distance because of friction from the groove.

It would keep going without friction.



The heavy ball will go farther. Although heavy ball has more weight and therefore more friction, the small ball rotates more so therefore it has more friction still. (The balls are fired along the groove)

Gravity pulls down the same on all the marbles therefore all would fall at the same rate.

The small one goes faster because its easier to get going.

All the balls would go on forever if there was no friction.

**Task 2.**

The ball and cart are separate objects so when the cart starts, the ball hits the back because it's still.

The cart and the ball move, when the cart stops, the ball is going that speed so it hits the front.

**Task 3.**

Astronaut would still be over the equator because he has no motion.

The spaceship has engines.

The earth is moving underneath the spaceman

The man would fall to earth under gravity.

**Task 4.**

Gravity pulls on the weight and the cart moves.

The cart will increase its speed because the weight pulls it down and the gravity gets stronger.

Force is greater closer to earth.

**James.**

**Task 1.**

The air and friction stop the ball.

With no friction the ball would go on forever.

Bigger ball has more mass, its harder to push and get going so with same force, small ball would go farther.

Big one won't go as fast so it doesn't have the right speed to keep going.

There's less force per density so big one will go slower.

The pull of gravity is greater on the big ball so it slows it down because there's more resistance.

**Task 2.**

The ball will go backwards at the start and forwards at the stop.

Newton's first law of motion.

**Task 3.**

The spaceman would stay in the same place relative to the spaceship unless he pushed himself away.

Wonders if the pull of gravity would have a different effect on him and the spaceship because of different density changed to mass. Otherwise he would stay with the spaceship.

On TV shows the spaceman is shown drifting away when he leaves the spaceship but doesn't think that is right.

If the spaceman pushes off in space, he should go one way and the spaceship the other.

**Task 4.**

When the weight touches the floor, the cart will keep going with its inertia.

A falling object increases its speed, so does the cart.

The cart will increase speed at a lower rate after it gets moving.

No, the acceleration will be constant.

When the string is longer, the cart will continue moving with its inertia after the weight reaches the ground but the cart will slow down.

Inertia is overcome by gravity and friction in the wheels.

Gravity and friction are the same, gravity pulls down and friction is between the body and the earth.

Friction acts downward.

**Marsha.**

**Task 1.**

The ball stops because there's not enough force. It needs energy to go to the end.

Energy makes it move.

The ball would go further if the rod sloped down.

The heavy ball won't go as far as the light one, because it has too much pull.

It's too heavy and it'll slow it down.

Lighter ball needs less energy to get a certain distance.

This one's big so for a bigger space it needs more energy.

**Task 2.**

The ball moves back at first.

Then it goes all around, then forward because the cart hit it.

The ball goes back because the cart moves and the ball doesn't.

(After a demonstration of the movement)

When the cart stops, there is a jerk so the ball goes forward.

(The demonstration was repeated)

The cart stopped, the ball was still moving so it went forward.

**Task 3.**

The spaceman will stay with the spaceship.

(This was immediately following Task 2 and it is possible that there was transfer from task to task).

If the spaceman pushes away out in space, he will just roam around.

After he pushes away, he'll just stay there.  
 The spaceship keeps going with the power it has.  
 The spaceman could get back to the spaceship if it  
 were stationary by walking.

**Task 4.**

The cart will move faster because falling bodies  
 move faster.

The weight gains energy as it's falling.

When the string is longer, the cart will go slower.

No, it'll go faster because it has more time to gain  
 speed, to gain energy.

It will go faster at first because the weight is  
 further back so the weight isn't pulling as much  
 with it.

**Bernie.**

**Task 1.**

While being pushed, the ball is accelerating, when  
 not being touched acceleration would start to  
 decrease and it wouldn't make the end of the track  
 with its speed.

The glass ball would go faster than the small steel  
 ball because less mass needs less energy to push it.

The largest ball with the same energy will go the  
 least far because it has more mass.

**Task 2.**

The ball will stay still at first and go back in the  
 cart a bit.

When the cart stops the ball will go to the hole in  
 the centre.

The ball will try to keep going when the cart stops.

**Task 3.**

The spaceman will stay with the spaceship because  
 he's going the same speed and there's nothing to  
 slow him down.

If he pushed away from the spaceship, he would keep  
 going in that direction.

**Task 4.**

The cart will accelerate because the weight gets  
 heavier and heavier.

The gravity would be pulling the lead weight down  
 towards it.

The weight is pulling the earth to it too but you  
 can't tell.

Gravity on the weight gets stronger and stronger as  
 it gets closer to the earth.

With longer string the cart travels longer and that  
 makes it go faster.

**Brian.**

**Task 1.**

The ball starts off fast then slows down because of gravity.

Power is given at first then no more is given.

Gravity and friction act on the ball.

If there was no friction, the ball would go further but it would stop because of gravity.

The glass marble is lighter and will go further and faster than the steel ball.

The heavier ball is harder to get moving and has more gravity to slow it down.

**Task 2.**

The ball moves back in the cart at the start because it's trying to stay still - that's Newton's First Law or something.

The ball keeps going at the end until it's stopped by the edge of the cart.

**Task 3.**

The spaceman will float behind the spaceship tumbling around

He won't go as fast as the spaceship.

He must be in the earth's gravity because satellites come down eventually.

If he was out in space, he would speed up because he pushed himself off.

Then he'd slow down and keep on going.

Probably wouldn't slow down just keep on going.

**Task 4.**

The weight must be heavier than the cart to pull it. But the cart has wheels so it would probably go anyway.

Gravity will make the cart accelerate.

With the longer string, the cart will accelerate until the weight reaches the ground and then will slow down.

**Shawn.**

**Task 1.**

The amount of energy released by the spring determines how far the ball goes down the track.

The energy is used up in getting from here to here.

The small ball has less mass, the energy isn't being used like that.

You don't have the energy to throw a big ball as far as a little ball. (The balls were the same size but one was heavier than the other).

The larger ball has more resistance because it has a larger surface area covering the tracks and there will be friction from the air around it.

It takes more energy to move bigger things.

If there was no friction at all the small ball would still go further because the force being applied would be used faster by the bigger ball.

**Task 2.**

On the start, the ball will roll back, on the stop, it will go forward.

Because to every action there is a reaction.

When you're in a car and throw up a ball, the car is going to change its space and that tends to move the ball back in a different position, maybe it's the same here.

On the sudden stop the ball goes forward because of reaction to the stop.

#### Task 3.

Spaceman stays with spaceship because if you're on hood of moving car, don't fall off when you let go. If the spaceman pushed himself off in space, he'll just float upwards because there's no gravitational pull in space.

He'll float to the extent of his force.

Perhaps it doesn't matter how hard he pushes, because of the gravity perhaps he'll move a certain distance and stop there.

#### Task 4.

Cart will start slow and then speed up.

The weight drops because of gravity and as it drops it increases speed and increases momentum and increases its energy.

The energy comes from the gravitational pull but gravity does not increase its energy.

With longer string it has the same motion except when the weight reaches the ground the cart will just carry on.

Anne.

#### Task 1.

Friction from the metal causes the ball to slow down.

If there was no friction, the ball would keep going. The bigger one won't go as far and the smaller one will go farther because it weighs less.

It's easier to get a lighter thing to move so if the force is constant it will go farther.

There is more surface area on the bigger ball.

#### Task 2.

The ball will go backward when it starts and forwards when it stops.

Continues with the motion it was in when cart stops. It moves back at first because it has been sitting in one place and would tend to continue sitting but can't, it goes back, I can't understand it.

Did this in Junior High but don't remember formulas or laws.

Forces acted on it and it takes a long time to react, that's what "they" said.

(After the demonstration) It sits there a little while and then goes back.

It goes forward at the end because it continues moving in the direction it was.

At the beginning, ball isn't moving, cart is.

**Task 3.**

Where spaceman is depends on how far out he is because there's less friction and gravity further out.

Would be behind spaceship

Would have to be fairly close because gravity holds it.

If he's orbiting, needs space-suit and therefore there wouldn't be any friction or very little.

May have engines on spaceship.

If no engine would still move at same rate unless close in.

Spaceman should be near spaceship after he let go.

If the spaceman pushes himself off in space, he starts a force acting on him while he is pushing and he keeps on going.

**Task 4.**

The weight is pulled down by gravity.

It will go at a steady speed until the weight reaches the floor.

(After the demo) The cart increases speed.

When the weight got closer to the ground, it was easier for gravity to act on it.

With longer string, the cart increases speed until the weight reaches the floor then it slowly decreases.

**Lisbeth.**

**Task 1.**

Ball will go along and stop because of the pull of gravity and because there's nothing hitting it all the time.

It would go further in a vacuum because there's no air.

The marble has less weight and it would go further and faster.

The steel ball won't go as far and will go slower. Gravity doesn't have as much space to pull down on the marble. (Marble is same size).

Large ball doesn't go as far because it takes more to push it and because gravity pulls down harder on it.

**Task 2.**

When the cart is first pulled, ball will go against the edge.

When the cart is stopped, the ball will go forward.

When the cart is pulled there has to be an equal reaction in the other direction.

When the cart is stopped the ball goes on moving forward because it's on its own.

(After the demo) When the cart is started, the ball doesn't move by itself.

Does it have something to do with gravity?

Task 3.

The spaceman will be up near spaceship  
Gravity keeps him into earth and the speed keeps him going.

It might be that because he's smaller, he would go slower than the spaceship.

As soon as an object is a certain distance above the earth it will go into orbit - between air masses?

It doesn't have enough force to leave the earth so it gets stuck in an orbit.

Away in space after pushing away from the spaceship spaceman will just stay away from it but quite close.

Task 4.

The cart moves because gravity acts on the hanging weight.

The cart starts slow then will move faster because gravity is greater near floor.

When string is longer, cart will increase speed until the weight gets the ground then it will decrease.

The cart slows down because gravity pulls on it and the air slows it down.

Doug.

Task 1.

The balls keeps going until it slows down because of gravity and pressure of air molecules.

The weight of the other balls makes a difference.

The weight on the spot compared with the pressure put on it varies.

The lighter object is easier to push.

It's easier to lift a light box.

Light ball goes faster and longer..

Task 2.

The ball will move around and hit the walls on start and stop.

The ground under the ball moves so the ball picks up ground and sticks to it and hits a wall and bounces off.

Will hit back first with a straight forward motion.

Its in the centre and gravity is in the middle so the ball will come back close to the middle.

The ball is held on the plate and the wheels are pulled to earth.

(Some talk about molecules in gases, solids and liquids).

Object will stay where it is because gravitational force is pushed toward it and reflected.

All molecules are racing towards it, reflecting off

and bouncing it so it stays there, in the middle.  
If it moves, a new current comes in, there's an offset.

If you pull in wall, air flow goes over and starts turbulence and that pushes it back.

At stop pushed forward.

(After demonstration) If it had moved in a curve, would have gone all over because of pressure.

With no air is plasma.

In space no gravity, no air, no oxygen.

What would happen if there was no air?

Well the ball and cart would probably move slower because there's no air on the moon and the guys there moved slowly.

#### Task 3.

The spaceman would stay on top of the ship because of gravity.

Just enough gravity to keep spaceship in orbit like planets and gravitational round sun.

If the spaceman pushed himself off in space, he would keep going until he slowed down.

He slows down by hitting molecules.

Could go on forever like asteroids.

#### Task 4.

Couldn't predict movement of cart because didn't know relative weights of cart and weight.

If the string was three miles long then weight of string would mean it wouldn't move.

Weight will pull because of pull to centre of earth and cart will roll to edge.

Gradually gains speed because the closer you get to earth, the faster you go.

Will not reach terminal velocity because too close to earth.

Gravity is stronger closer to earth.

With longer string should speed up then slow down.

Not enough room to get to maximum peak.

#### Anin.

##### Task 1.

At first the ball goes fast and then slow because there's not enough force pushing it to make it go. Lighter ball goes farther than heavier one because gravity pulls heavier one down.

Also there's not enough force to push it.

##### Task 2.

The ball would bounce around and hit the front.

(After demonstration) The wind pushes it to the back.

Went to the front because there's no more wind.

Ball is attracted back at start, when stopped went forwards.

The stop comes unexpectedly so ball thrown forward by gravity pull and down.



**Task 3.**

The spaceman will be at the same spot and drifting the other way because there's no gravity pull.

No, he'll drift to earth because of gravity pull.

He will be moving forward but will stop slowly and a little gravity will pull him to earth.

His speed down will increase because gravity pull increases.

If the spaceman pushes off in space, he will go on floating the way he pushed.

He might stop after a long time.

**Task 4.**

The cart will go forward at the same speed.

No, it will be slow here then gradually go faster.

Because gravity pull gets faster.

With longer string the cart will increase speed

until the weight hits the ground and then will go at the same speed.

David.

**Task 1.**

The ball will slow down because gravity pulling it against the steel causes it to stop.

If it wasn't for that it would go on forever.

All balls will go the same distance.

No gravitational pull is different will go different distances.

**Task 2.**

The marble will roll back until it hits the back and then it will keep going.

Gravitational pull pulls marble down so marble tends to stay in one place.

After the marble hits the back automatically does to the front like a change of force between the marble and wagon.

When the cart stops, marble doesn't so it goes on moving to the front.

**Task 3.**

The spaceman will stay over the equator.

He will stay with spaceship.

No over equator.

He is in a strict orbit so he won't be pulled to earth because of equal forces.

Like the moon is in orbit.

Perhaps gravitational of earth is balanced by the moon's own gravitational pull.

The spaceship keeps in orbit around the earth because the gravitational pull of the earth and sun keep it in orbit by balancing.

Same for the spaceman. Its the turning of the earth that makes him orbit.

When the spaceman pushed himself away in space he would go on moving away.

**Task 4.**

The weight of the hanging weight must be greater than the weight of the cart for the cart to move. The cart will increase its speed because the gravitational is greater as the weight falls. With longer string the cart will be moving faster at the end.

**Geoff.****Task 1.**

The ball would go so far and stop because there's not enough momentum.  
Gravity pulls it down to stop it.  
It would go on forever in space.  
The other balls would go the same distance.  
(After demonstration) The gravitational force is different explains different distances.  
Should be the same because in falling, movement is same for different weights, same shape.  
Maybe the bigger one catches more air.  
It must be because you need a bigger force to move a bigger object.

**Task 2.**

When the cart starts, the ball rolls to the back, when the cart stops, the ball rolls forward.  
The cart moves fast at first, ball doesn't.  
When the cart slows down, the ball moves back.  
The ball stays still, (G force) then the cart comes along and hits it.  
The ball goes on forward when the cart stops because of momentum - the weight and gravity.  
The ball is being moved by the cart, the cart stops and the ball doesn't realise so it continues moving.

**Task 3.**

The spaceman keeps falling like spaceship.  
He goes in a straight line.  
He follows the ship because of the orbit.  
The spaceman might fall back, depends on what difference the different weight would make.  
If he pushed off in space, he would go on moving unless another force acts.

**Task 4.**

Will go at same speed all the way.  
No, it will gradually increase speed because there's more of a pull.  
No then it'll go at the same speed.  
(After the demonstration) There's more gravitational closer to the ground.  
It's momentum, it starts off slowly then just gradually gets faster.  
When the string is longer, the cart will move slower.  
It'll have more speed when it reaches the end, it'll

move faster.

It'll go fast then slow down because it won't have the weight to pull it. The weight will have reached the ground.

Its weight pulled it after the hanging weight reached the ground. It didn't have any of its own power. It kept going by momentum.

**Barb.**

**Task 1.**

The ball will stop because it loses momentum.

The force behind it from the spring gets used up by air pressure and gravity slows it down.

The marble will go the farthest, the big steel ball the least far.

Need more force to make the larger ball go longer distance.

A large object needs a larger force to set it going, each molecule of mass needs a certain force.

The ball accelerates at first then slows down - the molecules can't keep up speed because of resistance.

The force of gravity keeps the ball on the ground so it doesn't go up in the sky and that produces friction which slows it down and air pressure slows it down

The marble went the furthest because there's less mass and more force on each molecule.

**Task 2.**

The ball will go forward at first and then backwards.

(After demonstration) No, the other way around.

The wagon was set in motion not the ball so the ball compensated for it by moving the other way.

The pull on the cart forced it the other way.

The ball started going the same force as the wagon then when the wagon stopped it didn't stop the ball so it kept on going.

Force keeps you going.

**Task 3.**

The orbit is outside the gravitational pull of the earth.

The spaceship goes in an orbit therefore the earth pulls it - magnetic pull? - gravitational?

The spaceman will fall to earth.

The spaceship is powered by engines.

The moon is out of the gravitational pull of the earth, magnetic poles keep it in orbit.

If the spaceman pushed away in space, he would just float away.

**Task 4.**

The cart will increase speed because once it gets moving it needs less force so it increases speed.

With a longer string, the cart increases speed until

the weight hits the ground the it slows down.  
After starting, the weight pulling on it means it goes faster.

**Tamara.**

**Task 1.**

The amount of force given to the ball makes a difference in how far it goes.

The glass marble goes further because it weighs less.

It's harder to push something that weighs more.

The heavier, bigger marble can't go as far with the same amount of force because there's more area to roll over.

**Task 2.**

The ball goes to the back at the beginning because it's being forced back.

It goes to the front at stop because the cart is stopped but the ball isn't.

(The demonstration was performed) At the beginning the ball stayed in its place for a minute and then went back.

No, the cart went forward but the ball stayed still.

**Task 3.**

The spaceman will be floating around as he does on television.

The spaceship has power.

Gravity holds things where they're supposed to be.

Maybe spaceman would go on round in orbit but he couldn't get to the spaceship because the spaceship is bigger and is being pulled around by gravity faster.

If he pushed himself off in space, he would just stay where he pushed himself to - where the force ran out.

He couldn't go on forever because there's nothing to make him move.

**Task 4.**

The cart should be lighter than the weight or it won't move.

It might speed up somewhere along the way.

(The weight was allowed to fall and pull the cart)

You could have a heavier cart because of the wheels.

The speed increases slowly all along.

With a longer string, it will go faster at the beginning and it will speed up faster because there's more room to speed up faster.

(After demonstration) It kept the same speed after the weight hit the ground.

Would slow down anyway if there was nothing making it go.

Wendy.

Task 1.

The force in pulling back the spring is used up by pushing the ball forward.

It slows down because the amount of force is used plus gravity and pressure slow it down.

Perhaps not gravity but the air pressure because it has to push its way through.

If track was infinitely long ball would go on forever.

The heavy ball needs more force to make it go because it's heavier and its weight prevents it from moving.

Large one would need more force to get it to move because it's heavier and the weight would prevent it from moving as quickly.

The little one would go further and faster because it's smaller and lighter; it doesn't have as much area.

Task 2

The ball moves back because it's staying in the same place and as the cart moves it appears to move back.

The ball continues to move when the cart stops because it still has the motion of the cart.

Task 3.

Is the spaceship beyond gravity? if not he'd be pulled down.

He'd follow spaceship for a little way, getting slower then fall in towards earth.

The spaceship has something pushing it.

He'd be pulled in because his mass isn't as great he'd be pulled in and slowed down because of air pressure and increased gravitational pull.

Gravity would pull on him quicker because he's easier to direct being less mass.

If he pushed off in space would go on forever.

Task 4.

The weight pulls down on the string and pulls the string..

This (the weight) is heavier.

It's got gravitational pull as well as its weight pushing down so it's going to pull the cord and the cart will move forward.

Weight includes gravitational pull, sorry, the mass and the gravitational will push down the cart.

Gravity gets stronger closer to earth and makes it move faster.

(After demonstration)

Its got the momentum of the object moving plus the weight and the gravitational force pulling it harder would cause it to move faster.

With the longer string will continue with the same speed after the weight hits the ground.

Wayne.

Task 1.

The ball will move a certain distance and then stop because of friction.

Without friction it would go on forever.

The glass ball is lighter, there is less friction so it goes further.

The heavy one has more friction so it won't go as far.

The air friction is greater with the big one.

The small one has less resistance against the spring so it will push it further and faster.

Task 2.

At the start, the ball goes to the back, at stop it goes to the front.

The ball is not attached to anything.

The atmosphere surrounding the ball holds it in place and prevents it from moving with the cart.

At the stop, the ball continues its motion and goes on.

Task 3.

The spaceman would be with the spaceship because there's a vacuum in space and there's nothing to slow him down.

The spaceship is in orbit because there's centrifugal force pulling out and gravity in.

If the spaceman pushed off in space would depend on the direction: If he pushed forward, he would go faster and away, if back, would go slower and away.

If he pushed sideways would keep same forward motion but move away sideways.

Task 4.

The cart speeds up because the falling weight speeds up.

Once it gets momentum, will build up momentum to the limit.

With the longer string would keep going until the momentum wears out.

Jane.

Task 1.

There's not enough energy passing from the spring to the ball to make it go all the way down.

Glass marble will go further because it's lighter and there's less gravitational pull on it.

Gravitational pull holds it back more holds it down to the ground more so it can't move as easily.

Large ball won't go as far because it has more gravitational pull on it.

Gravitational pull tries to hold it in one place.

Task 2.

The ball tries to go back at first, to the front on stopping the cart.

Ball is free moving and doesn't make the adjustment as quickly as the cart does.

(After the demonstration) The ball stays in the same place.

At the end the ball keeps going although the cart has stopped.

#### Task 3.

The spaceman would be at the equator.

Wouldn't be moving but it would seem he is moving because the earth is.

Air is only close to the earth, outside no atmosphere.

If there's no atmosphere, there's no gravity.

Something must keep the moon up but if there's gravity, why doesn't it fall to earth?

Something must hold spaceship in orbit not necessarily gravity.

If spaceman pushed himself off in space would drift away in the direction he pushed.

Then he'd be stationary.

Maybe not if there's no air to stop him.

#### Task 4.

The weight will pick up velocity because it picks up force or something as it goes faster and faster.

It increases speed because the weight is closer to the floor.

Gravity pulls harder as it gets down further.

No that's not true maybe there's more string on the other side of the pulley so there's more weight there.

With longer string after weight reaches ground, there's nothing pulling so cart will slow down and stop.

Brian.

#### Task 1.

The ball slows down and loses momentum because of friction on the sides.

If there was no friction, would keep going forever.

The small ball would slow down fast because it would wobble as it goes down.

The big ball would go on rolling because it would be riding on the rails.

The small ball will go faster, slow down faster big ball will go slower but keep on rolling.

(After the demonstration) Large ball is heavier and it has more mass to roll over.

#### Task 2.

When the cart goes forward, the cart goes back, don't know why.

At the end the ball keeps rolling because there's

nothing to stop it.

(After the demonstration) The cart moved under it, the ball stayed in the same place.

When the cart stopped the ball went on moving until it hit the wall.

**Task 3.**

The spaceman will fall down to earth. (The floor of the laboratory).

No, he'll come in like this (towards globe), because of the earth's pull.

No, he'll keep falling (down to the floor again) because there's nothing to propel him.

Probably the spaceship is propelled by rockets or something.

He might have momentum going down while spaceship has momentum going up, with the earth's pull, he might end up on the earth.

If he pushed off in space would just keep going if there are no forces acting on him.

**Task 4.**

There would be uniform motion all the way.

(After the demonstration) As its going down, the pulley's going faster and it started pulling along the string and it started going faster when it was going down so the gravity started pulling down more so the whole thing starts speeding up.

With longer string, will slow down when weight hits the floor because nothing is pulling it.

**Carman.**

**Task 1.**

The ball slows down because of friction and the air. A greater mass makes it go slower.

The big ball will go slower but will go as far because it has more momentum.

The small ball goes faster and goes the same distance.

(After the demonstration) It could be the smaller one goes further because there's less friction from the air because of the surface area and it's lighter.

If it's lighter, it can use the energy more efficiently.

The energy of the big one is absorbed moving against the air and moving the mass against the rail.

**Task 2.**

The ball goes to the back and then to the front.

It's inertia, the stationary ball doesn't want to move and the moving ball doesn't want to stop.

**Task 3.**

He should be along with the spaceship because its under the influence of the earth's gravity and he has less mass.

Gravity with less mass equally so he should stay in



the same orbit.  
If he pushed off in space, would just keep on going until he came under the influence of another gravitational field.

Task 4.

Cart will start at zero and gradually increase its speed because the speed of gravity increases.  
Gravity increases: It's 32'/s and twice that every second.  
After the 2nd second it will have travelled 96'.()  
Don't know why speed increases as it falls.  
If the string is made longer it'll reach its highest speed as the weight reaches the ground and then go on coasting.

Chris.

Task 1.

The distance the ball goes will depend on how far you pull back the spring.  
The small ball will go fastest and nearly down to the end.  
The larger ball will go slowest and the force wouldn't push it as far.  
The greater the mass, the harder it is to push it.  
Mass slows it down, the small weight goes fast so it keeps going quite a distance.  
The mass is causing the force not to push it as far because there's more of it to push.

Task 2.

The force of the pull pulls the ball back at first. Then the ball rolls forward.  
When the cart goes forward, the weight of the ball pulls it back but as the cart stops, the weight shoots forward.  
Gravity pull pulls it back, force is going one way, and weight is back there.  
When the cart stops the weight of the ball shoots forward.  
Gravity pull pulls it back, force is going one way, and weight is back there.  
When it stops, the ball has to go somewhere so it goes forward.  
Force pushes you forward in a car when it stops.  
The force pushes you forward in the car when it stops.

Task 3.

The spaceman will be around the equator moving slowly up after the spaceship in the airstream of the ship.  
There's no oxygen but there are other gases there.  
If there are no gases there, he'd probably stay over the equator.  
The moon stays up there probably because of the sun.

The spaceship is programmed to orbit the earth.  
 Saturn has moons therefore gravity must keep our  
 moon in to earth.  
 Therefore he would go with the spaceship or straight  
 up.  
 If he pushed himself off in space, he would just  
 keep going.

**Task 4.**

The cart will go faster toward the end. It increases  
 as the weight is gaining momentum.

It's going down the centre of gravity of the string  
 as it gets around, the weight of the string gets  
 heavier.

When the string is longer: After the weight is on  
 the ground the cart keeps going.

With the weight it probably kept constant speed but  
 when the weight's on the floor it gained speed.

Won't it gain more momentum as it's going if the  
 weight's just stopped whereas it's got a constant  
 pull so it would keep it at a uniform speed but when  
 it's near the bottom, I guess it's losing more, it's  
 not pulling on it so it's gaining its own momentum  
 from the weight.

A person falls because his weight's greater than  
 gravity.

Gravity is the pull of the earth, weight's my mass.  
 Weight is the pull of gravity.

**Eric.**

**Task 1.**

Ball will go down that way don't know how far and  
 don't know why.

The heavier ball won't go as far because it's harder  
 to push.

The lighter ball goes further because it's easier to  
 push.

**Task 2.**

When the cart first moves, the ball will go  
 backwards.

When the cart is stopped, the ball goes forward.

The ball goes at the same speed as the cart, when  
 the cart is stopped, the ball didn't.

(After the demonstration) The ball stayed a bit at  
 first and then rolled back.

**Task 3.**

(Has been told things keep going in space but if he  
 hadn't been told would have said spaceman would lag  
 behind spaceship).

The spaceman will be with the spaceship.

If he pushed off in space, would continue forever.

**Task 4.**

The cart will speed up as it goes.  
 Gravity gets stronger as it gets closer to the ground.  
 With longer string might speed up slower.

Tim.

Task 1.

After the push, the ball will go on increasing its speed for about two feet and then slow down.

It slows down because of friction and air resistance.

(After the demonstration) No, it stayed at a steady speed because after the first push, the friction started slowing it down.

The large ball and glass marble should go same speed and then slow down.

The heavier one will go farther, the lighter one less far because resistance has more effect.

The pressure, the weight and everything pushing against the smaller one will make it slow down faster.

(After the demonstration) The same force pushing against the heavier one would make it go slower - the friction would make it slow down faster because it isn't going as fast as the two.

If there was no friction or air they would all go for longer but they would all be pretty much the same.

No they would just keep going about the same speed.

Task 2.

The ball will go back on start and forward on stop.

(After the demonstration) When the cart is going the wind pushes the ball back.

When the cart stops, there's no wind so the sudden stop pushes the ball forward.

Task 3.

The spaceman would stay where he was, he wasn't moving, spaceship was.

(Analogy with ball in the cart) The force of you going along here, you would just keep going.

If he was trapped in the orbit, he would go round the earth but if there was no gravity, he would just keep going straight.

He'll be going slower than the ship because the ship will have its engines on so it would have a constant force.

If he pushed off in space would go on away at an angle.

Task 4.

The cart gradually picks up speed from zero.

With a longer string will go faster. (Thinks string will pull for longer) The cart slows down because of friction.

It speeds up because the weight is pulling.

Lonny.

Task 1.

The ball stops because it doesn't have enough energy to go further because of resistance.

If it had no resistance, what would it go on?

If there was no resistance, it would stop eventually because there's only a certain amount of energy.

The light marble will go further and the heavy ball not as far.

When you have that energy from the spring pushing against the heavy things, it slows it down under the resistance of this thing here because you need more power to push something heavier and if you use the same amount of power for the light thing, it should go further..

Task 2.

When the cart is pulled, the ball goes back.

When the cart is stopped the ball goes forward.

The ball goes back because of the force against the ball.

They're both still at the moment but when you pull cart, ball is still still but cart is moving and it moves - it backwards.

When you stop it the energy's still in the ball now both of them are moving at the same speed, but if you stop it the ball will go forwards because it still wants to go.

The acceleration of the cart makes the ball go backwards - G-force.

Task 3.

He wouldn't be with ship but maybe he would because there's no resistance in space.

But you couldn't go out there and keep going.

The earth's gravity is keeping the spaceship in.

Rocket power keeps it going.

If spaceman pushed himself off in space, would keep on going.

Task 4.

The cart will increase its speed because the weight increases its speed.

Gravity makes the cart fall faster because it pulls it down.

If the string is made longer, the cart will slow down after the weight hits the ground.

Lawrence.

Task 1.

The ball slows down because there's no force pushing it but the sudden force just pushed it.

If you were to pull this thing and let it go it

would roll for aways and then stop because the force is still on it.

Could make it go further by lubricating the sides. That would make it slide through more, might go a little bit further but not much.

On smaller ball gravitational pull is less so the force needed to push it is less.

#### Task 2.

The ball will go to the front when the cart stops and to the back on a sudden start.

The sudden pull makes the ball move, the force from you pulling the cart pushes the ball to the back.

The sudden stop compelled the ball to go forwards. You suddenly stopped it, the ball was still going forwards.

At the beginning, the ball was standing still and when you pulled it the same kind of thing happened, you pulled it and the thing sort of went out from underneath it and the ball just went to the back end.

#### Task 3.

The spaceman will lag behind the spaceship and drift.

Very little gravity in space, the man is weightless so will drift like wood on water.

The spaceship has propulsion so man couldn't keep up unless he was powered.

If the man pushed himself away when they were way out in space, he would probably stay from where the force ends.

#### Task 4.

The cart will speed up because of the gravitational pull on the weight.

With longer string should speed up faster - no should go the same because even though it does have longer string, it still has to go the same distance down.

#### Claren.

##### Task 1.

The distance the ball goes depends on how heavy you pull that spring.

The mass of the big ball is heavier so it's going to take more strength to travel the same distance.

Gravity pull pulls you down but no, the ball is travelling "all the ways" and the gravity just up and down.

Lighter things travel faster like lighter people.

##### Task 2.

The ball will hit all of the sides.

(After the demonstration) The cart's not moving, it's staying still then you move the cart and the cart is in motion and the ball hits the back.

**Task 3.**

The spaceman will float around over the equator. Gravity effects him but he won't come down because gravity isn't much.

It could be that he won't come down because there'd be interferences from other gravities.

Could be the sun's energy. It's really hot there because it has no atmosphere just outer space.

The moon has a gravity to earth but it doesn't land on it.

If the spaceman pushed himself away in space, he would go on and never stop.

**Task 4.**

The cart moved faster because the distance to the pole (pulley?) was shorter.

Harold.

**Task 1.**

The small ball travels faster and further because it's small.

It goes faster because it hasn't much weight.

It goes further because it's faster.

The heavier one gets stuck to the sides more.

If you could make it smoother it wouldn't go any further, it would just have a nicer run.

**Task 2.**

At the start the ball goes to the back, at the stop it goes to the front.

At the start it's settled in its place, when you pull it it jerks and pushes back.

At the stop, all the force goes forward and pushes it to the front.

Before braking in a car, you're sitting back in the seat, you're not moving. When you stop, the car pushes you forward, all the weight ends up in front.

**Task 3.**

He'd be floating up into orbit.

No, he'd be going down to the desk, because he has no oxygen.

(It was explained there was oxygen in the spaceman's pack.

Then he'd be going up because gravity's light and pushes you up.

Gravity comes under you and pushes you up.

If it wasn't for gravity you would sit on the floor.

You stay on the ground because of your force - gravity tries to push up but your force is heavier and keeps you down.

The earth goes round the moon.

The sun goes round the earth once a day.

Sometimes it's cold weather and we get rain.

Rain falls or we have snow.

The moon's light is from the sun. Clouds cut off the

light to give full moon, quarter moon etc.  
If the spaceman pushed himself off in space, he'd come back down.

**Task 4.**

The speed increases gradually.

The air pushes it, gathers it in like a vacuum and makes it go faster.

No, I don't think so; the weight is falling down, pulls it, it goes by itself and the weight is pulling it faster.

With the longer string, it slows down after the weight hits the floor because the weight isn't pulling any more.

**Alan.**

**Task 1.**

Just the force from the spring makes the ball go that far.

The lighter ball goes further because it's easier to push a lighter object.

**Task 2.**

When the cart starts, the ball goes to the back.

When the cart stops the ball goes to the front.

No idea why.

The ball isn't moving before the cart stops.

**Task 3.**

The spaceman will still be orbiting earth but a little further out because he's lighter.

He would orbit earth a couple of times and then drift off into space.

If he pushed off in space, he'd go on forever.

**Task 4.**

If the weight is heavier than the cart, the cart will move with slow acceleration.

Increased speed is because of the pull of the weight, because of the speed of the weight.

With longer string, the speed went down when the washer hit the floor and cut off.

**Bill.**

**Task 1.**

Energy given to the ball by the spring slowly decreases because of friction.

The glass ball is lighter so there's less friction.

The larger ball goes slower because there's more friction because it's heavier.

**Task 2.**

When you first pull, the ball will go to the back, when you stop, it'll go to the front.

The ball will go back at the start because it's not being pulled as well.

The cart is moving under the ball which isn't

moving.

The motion of the cart continues and stops so the ball goes forward.

**Task 3,**

The spaceman will slowly follow the orbit because he doesn't have the energy to push him.

He will be going down into earth.

He slows down because there's nothing pushing him.

The spaceship has a rocket.

The spaceship is orbiting because it's between the moon's and the earth's gravity forces.

Things which go on moving slow down as the energy disappears.

The energy just goes to nowhere. If the spaceman pushes away from the spaceship in space, he'd go on moving forever.

**Task 4.**

The cart picks up speed at first and then goes at a constant speed. (After the demonstration) it still does that.

When there is a longer string, the cart slowed down after the weight hit the floor.

It increases speed while the weight is pulling it. (Rather contradictory statements)

**Richard.**

**Task 1.**

The spring pushes the ball until it has enough force to move down the track then it will slow down.

The mass slows it down.

The slower it goes, gravity starts to react on it.

Gravity pulls downward and if there isn't enough momentum sideways, gravity will slow it down and stop it.

The marble goes further because gravity isn't pulling down as much on it.

**Task 2.**

The ball wants to keep moving so goes forward at the end.

At the beginning, it wanted to stay still but the cart moved so it stayed still till it hit the back of the cart.

**Task 3.**

The spaceman will be between the spaceship and the equator but coming in to earth because of gravity.

The spaceship is powered, he isn't so he'll slow down under conditions of gravity.

He'll fall below the line of the orbit.

The moon doesn't need engines because it's far enough out not to feel gravity so much.

No, he won't slow down so he'll stay the proper height.

If he pushes off from the spaceship he'll go on



moving forever.

Task 4.

The cart will accelerate from the start to the end. Gravity pulls on the weight, the more it pulls, the faster it falls.

With the longer string has more time to speed up.

Will speed up until the weight reaches the ground.

The weight of the cart will slow it down.

Greg.

Task 1.

The force hitting the ball will drag it to the end. It loses velocity because there's nothing pushing it.

It needs something pushing to keep it going.

The marble goes further and the big steel ball less far because the spring only gives off a certain amount of power.

Task 2.

When you pull the cart suddenly, the ball goes toward the back, as it goes, the ball moves along to the front. (Changed mind about ball moving gradually to the front and said it will stay at the back until you reach the end.)

Goes to back at first because the motion makes it roll.

(After the demonstration) As the cart was accelerating, the ball moved back but when it started to slow down the ball moved forward.

When going faster, crainge (?) holds it back.

As slowed down, ball moving at certain speed and moved forward.

Task 3.

The spaceman will be up above spaceship because there's no gravity.

spaceship kept in so there must be gravity so he'll stay with spaceship.

Away from earth after pushing off will just float around - keep on floating away.

Task 4.

The cart will go at a constant speed - accelerate a bit.

Because weight is falling at same rate.

No falling things accelerate so cart will because string is pulling it and cart tries to keep up.

Things fall when there's nothing to support them.

Things go faster from a great height because of the weight wants to find something to land on.

With longer string won't go as fast. (After the demonstration) no, its the same.

When the weight hits the ground, the cart goes by itself because there's nothing pulling it.

It accelerates when there's something pulling it.

The falling weight accelerated because it was being pulled by gravity.

**Karen.**

**Task 1.**

The force of the spring action pushes the ball down to the end.

When you pull the spring back, it increases the potential energy. When you let the spring go, it releases the potential energy which pushes the ball.

The bigger ball goes less far because it's heavier.

It's harder to push a big ball.

They went so far because of their mass.

**Task 2.**

The ball moves to the back at the start and to the front at the stop. (But she doesn't know why.)

It's the opposite to what happens to the wagon.

This happens in a car.

The ball wants to stay in the same place because energy is given to the wagon not to the ball.

The ball wants to keep going at the end.

**Task 3.**

The spaceman will be over the equator.

No, he's moving so he'd be between the spaceship and the equator.

He doesn't have force thrusting him forward as the spaceship does.

Oh no, the spaceship turns off all its engines it drops them so he would be up by the spaceship.

If he pushes off in space, he would keep going.

**Task 4.**

The cart is going to move forward because of the weight on the other end of the string.

There will be a gradual increase in speed.

The weight has more weight than the cart.

With the longer string, the cart will go faster and faster even after the weight touches the floor.

(After the demonstration) After the weight touched the ground the cart started to slow down again because the pull was taken away from it.

**Heather.**

**Task 1.**

The spring pushes the ball along.

The light marble goes furthest because it doesn't take so much to make it go down.

The big one needs a bigger push to push it.

**Task 2.**

The ball will go back then move around.

(After the demonstration) It goes forward on the stop. Otherwise no answer.

**Task 3.**

The spaceman would be still over Africa moving in the direction of the spaceship.

If he was out in space, he would be moving in the direction that he pushed.

Don't know whether he would stop.

**Task 4.**

The cart will start fast then slow down.

Falling things go at a constant speed.

(After the demonstration) It sped up.

With longer string it will move slower. (No reason why)

(After the demonstration) It increased its speed to a certain place then stayed the same.

**Grant.**

**Task 1.**

The lighter one won't go as far.

The heavier won't go as far because there's more to push on it and it uses up more energy as it hits it.

The spring has more energy when it hits the little ball.

(After the demonstration) When the spring hits the little ball, it doesn't have to use up as much force to get going as it does with the bigger one.

The little one had more push at the beginning.

It's lighter and will go further doesn't need more push.

**Task 2.**

The ball goes to the back on start and front on stop.

The ball is stationary at first, the cart moves.

At the end the ball continues moving.

**Task 3.**

The spaceman will be moving towards earth where he got off.

He would splat - no, would burn up.

Don't know why spaceship doesn't burn up.

If the earth disappeared, spaceship would go on until it hit another orbit.

It goes around earth because it's in orbit.

The earth is pulling on the spaceship.

If the spaceship disappeared, man would fall.

The spaceship has power, man doesn't.

If the spaceman pushed away in space, he would keep on going up.

**Task 4.**

The weight must be heavier than the cart.

It will go at a constant speed.

It will go faster as it gets closer to the ground because the earth is pulling on weight.

With longer string cart will take longer to go faster because there's more length in the string.

(After the demonstration) It went the same as before.

Peak speed in the centre because the weight hit the bottom.

It would go faster with shorter string.

**Deborah.**

**Task 1.**

It will go a way along and then go back.

(After the demonstration)

It went as far as it did because that was all the force there was in the spring.

It must have force to push it.

The glass marble will go further, the big one won't go as far.

The speed is different because of different weights.

The big one didn't go as far because of the weight behind it. (Expected balls to rotate back because there's no push left in them.)

**Task 2.**

The ball will go back on the start and forward on the stop.

Force is against the object to push it back and then behind the object.

(After the demonstration)

When you pulled forward your force was in front of it.

Your force changed on the stop but there's no force there.

**Task 3.**

The spaceman would go out into space because there's no pull or anything out in space.

He weighs lighter in space because there's no oxygen.

What little force there is is pushing him out into space.

He would die and his body disintegrate because he's so light and there's no oxygen.

If he pushed himself away in space, he would go that way because of momentum, force, gravitational pull.

(There's no gravity up there)

Then he would just stay where he pushed himself to.

**Task 4.**

The cart will get faster near the middle.

It might increase speed all the way.

It will have a constant acceleration because of the weight falling.

(After the demonstration) With longer string it will go slower because it takes longer to get to the cart.

It won't increase its speed as much as before. It will stay at a constant speed from the middle.

(After the demonstration) It went faster at the end.

It was more of a constant speed all the way through but it seemed to go faster at the end.

It increases speed because the weight is dropping.

Ted.

Task 1.

The block of wood will hit the ball and cause it to move down the track.

The further you pull it back, the more power it'll have coming up so the further it will go.

The momentum will hit it suddenly and it'll go further.

(After the demonstration) There's more pressure behind it and the acceleration of the block of wood on the spring will hit it and it'll give off some of that acceleration by hitting it and cause it to move down further.

The large ball will go less far because the more weight it has, the harder it is to move down because it stays stationary.

It'll slow down because it only has so much momentum going for it.

Friction maybe on this will slow it down.

Task 2.

It will hit back on go and front on stop.

The marble will stay still while the cart moves then will continue moving when the cart stops.

Task 3.

The spaceman would shoot out if the gravity's weak enough.

The spaceship is being controlled by the speed it's going and by gravity holding it in.

If the spaceship disappeared and gravity was great enough, he'd just come back around.

There must be gravity then so he should keep coming around but not as fast as the ship because he's lighter mass than the ship.

He'll probably go along with the ship and be a little ways behind it.

If he pushed off in space he'd just keep going because there's so little up there.

Task 4.

The weight will drop and pull the cart along.

It will have a steady acceleration because the weight attached to the string is pulling on it causing the force to move this way because of the force going down.

With longer string accelerates to a point then slows down.

Has the same acceleration.

## APPENDIX 3

## THE CRITERION TEST

The questions asked in the criterion test will be followed by the task to which it has some affinity, the number of students scoring full marks or part marks on the question, ( $N = 36$ ) and the degree to which it correlates with any concepts measured.

## PHYSICS 10

## Motion

1. A cyclist travelling at 6.0 m/s comes to rest in 3.0 s. What is his acceleration?

## Task 1.

33 students scored full marks,  
3 made minor errors and scored half marks.

2. In an ice-cream parlour, a waitress slides a 200 g sundae with an initial velocity of 5.0 m/s along the counter. If it comes to rest in front of the customer 2.0s later, what is the opposing force between the bottom of the sundae and the counter?

## Task 1.

16 students scored full marks,  
13 scored part marks,  
7 scored zero.

Correlated with end of term,  $r = 0.6$ ,  $p < 0.001$

3. A sports shoe manufacturer only produces two types of running shoe. The "Alpha" shoe has extremely good grip between the soles and the ground. The "Delta" shoe is more comfortable, has good grip but not as exceptional as the "Alpha" shoe. Which shoe would the sprinter prefer? Which would the long-distance runner? Why?

## Task 1.

18 students scored full marks,  
17 students scored part marks,  
1 student failed to score any marks on this question.

Correlated with success on task 2,  $r = 0.4$ ,  $p < 0.01$

4. A 1.0 kg ball dropped from a building strikes the ground 5.0 s later. If a 5.0 kg lead ball, the same size had been dropped instead, what time would it take to fall the same height?

## Task 4.

25 students answered correctly,  
11 students answered incorrectly or did not attempt.  
Correlates with success on tasks 1, 2 and 3.  $p < 0.05$   
Correlated with end of term marks,  $r = 0.7$ ,  $p < 0.001$

Correlated with explaining the motion of the ball in the cart by a force,  $r = -0.5$ ,  $p < 0.01$   
 Correlated with success in task 2,  $r = 0.3$ ,  $p < 0.05$ .

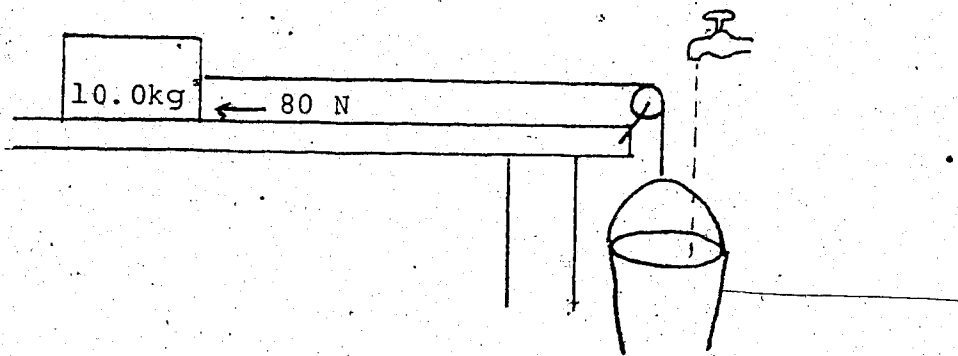
5. A car is moving at 12.0 m/s. If it accelerates to 18.0 m/s in 10 s, what is its acceleration?

Task 4.

28 students scored full marks,  
 2 scored part marks,  
 6 students scored zero.

Correlates with end of term marks,  $r = 0.4$ ,  $p < 0.02$   
 Correlates with task 4, gravity gets greater near earth,  $r = -0.4$ ,  $p < 0.05$   
 Correlates with use of force to explain the ball in the cart,  $r = -0.4$ ,  $p < 0.02$   
 Correlates with the belief that the spaceship had engines,  $r = 0.3$ ,  $p < 0.05$

6.



A mass of 10.0 kg rests on a bench. It is attached by a frictionless pulley to a bucket into which water trickles from a tap. If the force of friction between the mass and the bench is 80 N, what will the bucket and water weigh when the mass begins to move?

Task 4.

8 students scored full marks,  
 2 scored part marks  
 26 scored zero.

Correlated positively with students saying that the weight must be heavier than the cart in order to pull it in task 4,  $r = 0.4$ ,  $p < 0.02$   
 Correlates negatively with students saying that heavy objects need more push in task 1,  $r = -0.4$ ,  $p < 0.02$

7. A carton falls off the roof of a truck moving at 30 m/s as it passes a policeman. If it takes 1.0 s to reach the ground, how far from the policeman will it land?

## Task 2:

20 students scored full marks,

16 students scored zero marks.

Correlates with sophistication of first replies to tasks 1 and 3,  $r = 0.4$ ,  $p < 0.01$

Correlated with saying an accelerated body goes faster because it gathers momentum,  $r = 0.4$ ,  $p < 0.01$

8. A paper-boy riding his bicycle south at 4.0 m/s throws a paper to his left (east) at a horizontal velocity of 3.0 m/s relative to him. What is the horizontal velocity of the paper relative to the ground?

## Task 2.

21 students scored full marks,

15 students scored zero marks.

9. How can an astronaut on a journey to Mars under conditions of weightlessness distinguish between a rock of mass 50 kg and one of mass 500 kg if they appear exactly the same in all other ways?

## Task 3.

8 students scored full marks. 3 students had a partly correct answer. 25 students scored no marks.

10. Some students in a van are trying to drop pennies in a cup on the floor of the van. If they released them from a height directly above the cup, where do the pennies fall when
- the van is moving at a steady speed?
  - the van is accelerating?
  - the van is slowing down?

## Task 2.

28 students scored full marks.

8 students scored part marks.

11. A spaceship is way out in space. Draw a rough velocity-time graph for two minutes if it accelerates from a velocity of 1 500 km/h to 3 000 km/h for the first 30 s and then switches off the engines.



## Task 3.

16 students scored full marks.

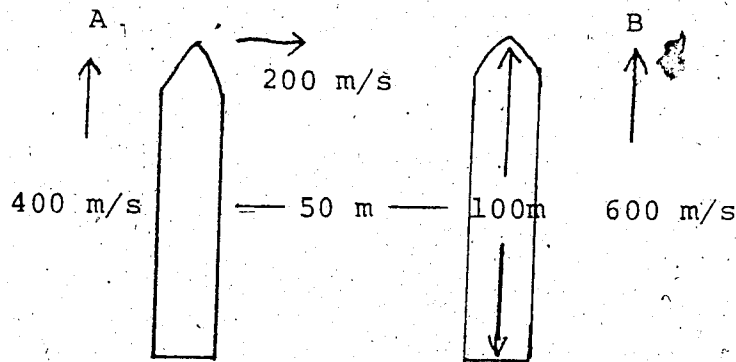
11 scored part marks.

9 students scored zero.

Correlates with end-of-term marks,  $r = 0.4$ ,  $p = 0.02$ .

Correlates with the conception in task 1, "it stops because it runs out of push",  $r = -0.65$ ,  $p < 0.001$

12. Space-ship B moving at 600 m/s passes space-ship A moving at 400 m/s in the same direction only 50 m away. At the moment that the ships are even, the captain in A fires a missile from the front of A in the direction of the front of B. If the missile travels at 200 m/s between A and B and the ships are 100 m long,
- how long will it take the missile to reach B?
  - where on B will it land?



## Task 3.

8 students scored full marks.

14 students scored part marks.

14 students scored no marks or did not attempt.

Correlates with performance on task 3,  $r = 0.39$ ,  $p = 0.02$ .