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CHILDREN'S BELIEFS ABOUT FREE-FALL MOTION

by

KENNETH C. KUHN

B.Sc., University of British Columbia, 1964
S.T.B., Vancouver School of Theology (U.B.C.), 1967

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Department of Education

The University of British Columbia
2075 Wesbrook Place
Vancouver, Canada
V6T 1W5

Date Aug. 28, 1979

ABSTRACT

Students' beliefs about free-fall motion were explored using structured interviews. The sample of 24 students was composed of 6 students (3 boys, 3 girls) selected from grades 6, 8, 10 and 11 respectively. Three sets of tasks involving one actual experiment and a number of simulated thought problems were used to investigate (a) the student's beliefs about the motion of a single object, (b) the relevance of the variables of height difference, initial velocity difference, frame of reference difference and weight difference for two objects and (c) the combined action of these factors when more than one was present. It was found that the interview methodology and tasks used were effective for collecting the data required in an exploratory study of this type. It was possible to categorize the mode of action of each variable in terms of: (a) not operating, (b) as operating in a short impulse only, (c) as operating but slowly dissipating, or (d) as operating with a continuous action. Examples of most response categories occurred at all levels but a number of possible developmental trends by grade were evident. Also there was a possible indication of the resistance of certain intuitive

beliefs to standard kinematics instruction for the grade 11 physics group. The results of this study could be useful to the classroom teacher as well as to the designer of a science curriculum. It suggests that students are able to explore some problems of motion beginning at the grade 6 level; that they should be allowed to explore the relevance of related variables; and that they should be encouraged to express and explore their own beliefs which they bring to the classroom about motion.

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CHAPTER ONE

1.00 INTRODUCTION

A number of perspectives for curriculum development and instruction stem from cognitive theory. Two of these are at the centre of Piaget's theory of intellectual development. The first of these is the role of skills in logic and reasoning as prerequisites for learning concepts. This perspective has been used extensively in research concerned with the acquisition of a variety of science concepts (Lawson and Wollman, 1976; Renner, 1976). Such research has generated a number of insights useful for classroom instruction.

The second perspective is the role played by the beliefs and concepts about a phenomenon brought by the student to the classroom;

> that is the *substance* of the actual beliefs and concepts held by children. Piaget refers to this distinction as physical or experiential knowledge as contrasted with operational or logico-mathematical knowledge.
> (Erickson, 1979, p.221)

This perspective has not been used as extensively in research. However it has generated a number of recent investigations. (Driver and Easley, 1978).

Some of them produce suggested strategies for teaching (Walters and Boldt, 1970; Barnes, 1970). Also some curriculum projects (Tiberghien and Delacote, 1976) have used this perspective.

Certain limitations may be placed on the ability of students to learn certain science concepts by the logical complexity of the concepts. However, a student requires more than logic alone to understand a concept (Robertson and Richardson, 1975). If this is the case, more than the students' ability to apply the logical steps involved in a concept merits investigation. Whittaker (1975) among others has suggested that it would be most valuable to determine the student's way of thinking about a concept.

> On the related issue of the use of Piagetian tasks for assessing pupils' development in science, it would seem that more valuable information could be gained by both curriculum developers and the practising teacher through interviewing pupils in order to understand their ideas and ways of thinking about a topic in question (Whittaker 1975) rather than as a device for classifying pupils and prescribing programmes for them. (Driver and Easley, 1978, p.79).

The present study is an investigation of students' beliefs about objects in free-fall motion. It was, therefore, conducted from the second perspective. Free fall motion merits investigation for a number of important reasons: (a) Concepts of motion are central to the physics curriculum (kinematics); (b) Free-fall involves very rapid acceleration. It is more difficult to apply "everyday" notions since it is a more subtle regularity in nature. This makes it more of a conceptual problem. In addition, a variety of conditions of position, initial velocity and weight can easily be arranged; (c) Motion is a central component of many experiences which do not involve formal instruction and, therefore, students' concepts of motion are influenced by these independent sources of belief; (d) A number of related concepts such as those of force and energy are involved as well.

The interview methodology (a modification of the Piagetian clinical interview) was chosen to collect the data. Based on previous experience (Kuhn, 1978) it was anticipated that this interview methodology would generate a rich bank of valid and reliable data.

Hypotheses were not defined as would be required for an experimental study. As a result, the study was clearly descriptive and exploratory. This type of preliminary investigation can be extremely useful for later experimental studies. It should be possible to generate fairly specific hypotheses for further research from the results of this study.

The study was exploratory because students' beliefs about motion have not yet been addressed by research to any significant extent. Consequently, it was not possible to predict in advance exactly which patterns of belief would emerge. However, certain specific beliefs were examined in the context of the tasks which were designed for the study.

1.10 SPECIFIC PROBLEMS

Students' beliefs were analysed in three areas:

(a) What are the characteristics of motion of a single object in free-fall?

(b) How relevant are the factors of height, initial velocity and weight to the motion of two objects in free-fall as seen from both an external and an internal frame of reference?

(c) What is the combined effect of these three variables when more than one variable is present?

In addition to the beliefs themselves, the sources of the beliefs were sought. Explanations for the beliefs were solicited using additional probing questions. More specific questions are given in Chapter Three where the tasks are discussed in detail.

1.20 METHODS OF STUDY

1.21 Data Collection

The structured interview methodology used to collect data was similar to that employed by Nussbaum and Novak

(1976) in their study on children's concepts of the earth. A standard protocol was employed (the same questions were asked in the same order to all subjects).

In addition to this standard protocol, explanations were sought by additional questioning. An audiotape cassette recorder was used to obtain accurate records of the interviews. Verbatim transcripts were prepared from sections of the interviews to be used in the analysis of the data.

1.22 Tasks of the Study

The tasks which were used in this study were developed by the author. They were based on the results of an earlier investigation (Kuhn, 1978). Also they were pilot tested using two separate class groups of physics 11 students. Responses to the tasks were in a written form. In addition, several grade 10 and grade 11 students were individually interviewed to determine the suitability of the tasks for an interview format. The tasks employed taught experiments using an apparatus novel to the students (Fig. 3.1). Indoor shotputs were used as falling objects, photocells were used to detect the motion and a digital device was used to display the times involved. Both the tasks and the apparatus are described in detail in Chapter Three.

1.23 The Subjects

There were two considerations which influenced the selection of subjects. On the one hand, it was anticipated that some developmental trends might emerge from the data. Thus, six students (three boys and three girls) were selected respectively from the grade 6, 8, 10, 11 levels resulting in a total of 24 interviews.

A second consideration was to examine the effect of beliefs about free-fall motion held by students who had just finished an instructional unit on iinematics. A sample of six (three boys and three girls) students enrolled in a Physics 11 course was used. One of the main intentions was to see if common-sense beliefs which are not necessarily consistent with the formal concepts which they had dealt with in their instructional unit on kinematics would tend to persist in spite of such instruction.

All students were selected from an elementary and a secondary school in North Vancouver, which are adjacent to each other.

1.30 EDUCATIONAL SIGNIFICANCE OF THE STUDY

Motion in the common-sense world of experience is significantly different from motion as described by kinematics formulas. Kinematics formulas apply in an ideal world without complications of friction, for example, and in isolation from related notions. In the common-sense world motion is experienced with related forces and applications of energy. Children form concepts of motion in this world of experience without any formal instruction. They carry these beliefs about motion with them to their formal experiences in the classroom. These do not necessarily match the formal description of the concepts in the curriculum. These previous beliefs may not simply be replaced by the formal concepts. A variety of other possibilities exist. For example, the student may keep both separate in his mind, or he may simply become confused. In any case it is useful for the educator to be aware of the specific nature of these beliefs.

The results of this study can relate directly to educational practice. For example, changes in the curriculum and in instructional strategy could be made to specifically allow for the accommodation of the beliefs identified. Teacher behaviour toward the student would also be aided if they were aware of the students' beliefs. The teacher would be inclined to consider the significance of the students' beliefs. They would be inclined to create an atmosphere in the classroom where the student felt at ease in expressing and exploring these beliefs.

1.40 LIMITATIONS OF THE STUDY

1.41 Developmental Aspect

In this study it was assumed that an interview methodology was effective in identifying genuine beliefs of students. However, there are limitations to the interview methodology. First, it limited the size of the sample. Consequently, the sample cannot be considered representative of a wide population. Inferences made must therefore be guarded. The number of responses in each category may not represent exactly the number of responses for a wide population. That is perhaps less important than the fact that the genuine patterns of belief should be identified. These patterns of belief could very well be represented in a wider population. Second, the interviews were time-consuming. Consequently, they had to be conducted over a two-month period. The spring break also occurred in the middle of the series of interviews which again protracted the time. Students were requested not to discuss their interview experience, and, as far as could be determined, they did not. During this period there was also an extensive media coverage of the Albert Einstein Centennial Celebration accompanied by discussion of his ideas concerning motion and relativity. There was not even an offhand reference to this in the explanations, so it was assumed that it had no significant effect on the results.

There are also possible limitations to the effectiveness of the tasks employed. They were pretested, but their reliability and validity were not extensively investigated.

Also the tasks themselves may have been limiting. Other important beliefs about free-fall motion not specifically related to the tasks used may not have been identified.

1.42 Instruction Aspect

There were a number of additional limitations specifically related to the problem of investigating the effects of instruction on students' beliefs. In addition to the fact that only a very small sample was used, interviews were conducted after the instruction occurred. No data was collected for beliefs occurring before instruction. Also, the nature of this instruction was not carefully controlled. It must be noted, however, that Physics 11 is an elective academic course and tends to draw its enrolment from the more able segment of the student population. These students tend to perform better than the average after formal instruction. They should have a better understanding of the formal concepts of kinematics after instruction than the average grade 11 student. Therefore, intuitive beliefs noted to persist after instruction, even for such a small group, would be significant.

CHAPTER TWO

BACKGROUND OF THE STUDY

2.00 INTRODUCTION

In this chapter the related literature will be reviewed in the following three areas:

1) The broad problem area of students' development of science concepts.

2) The more specific problem area of students' development of the concepts of speed and acceleration.

3) The implications of these research findings concerning the development of science concepts for curriculum and instruction.

2.10 LITERATURE IN THE BROAD PROBLEM AREA

2.11 Two Perspectives

The problem of the development of science concepts in students has been extensively investigated and reported in the literature. At least two different perspectives are evident in these investigations. These are the nomothetic and ideographic perspectives, (Driver and Easley, 1978).

In nomothetic studies the students' acquisition of the structure of theoretical concepts which reflect contemporary scientific knowledge is paramount.

> ...there are studies in which the pupils' understanding is assessed in terms of the congruence of their responses with accepted scientific ideas. Having specified such a standard the research task is then to assess the degree to which pupils' understanding conforms to that standard, the age and order at which certain ideas develop and to indicate common deviations from such an accepted view.
> (Driver and Easley, 1978, p.65)

From the nomothetic perspective readiness for concept learning is also of major concern.

> A major inhibitor to concept formation appears to be maturation as a function of age level. Younger children do not possess the ability to think abstractly and their concept classifications may not have progressed much beyond grouping.
> (Voelker, 1975, p.12).

Researchers working from this perspective are interested in establishing age or grade norms and seeking a sequence of concepts which can be presented in terms of their difficulty. They contend that sequencing of science concepts in the curriculum is usually not based on research findings but on other factors (Voelker, 1975, p.5). However, the organization for learning of concept sequences and the placing of students at the proper point in these sequences by grade has proven to be very difficult.

In ideographic studies the students' alternative frameworks are of central concern. These look "more fundamentally at the pupils own understanding and its development" (Driver and Easley, 1978, p.61). It is assumed here that the student develops science concepts from his concrete experiences in a common-sense world and not only from formal science instruction. These concepts are not simply misconceptions, but constitute alternative frameworks:

> ... it is the problem of the alternative frameworks which arise from students' personal experience of natural events and their attempt to make sense of them for themselves prior to instruction, on which ideographic studies mainly attempt to throw some light. Here the focus is on an individual's personal experience. (Driver and Easley, 1978, p.62)

In addition, it is suggested by some researchers that preconceptions (Ausubel, 1962) are "amazingly tenacious and resistant to extinction" (Driver and Easley, 1978, p.61). There is some evidence that students have great difficulty in accommodating their thinking to new experiences presented by instruction (Driver, 1973). Many commom-sense (Walters and Boldt, 1970) views of the world could, in fact, be found among the adult population.

This indication of the resistance of common-sense ideas to instruction does not necessarily mean that instruction is useless or that the ordering of concepts is not an important issue. Rather, it means that the ordering of concepts is not only a matter of logical complexity. Psychological ordering (Driver and Easley, 1978) of concepts by difficulty involves other factors such as the degree to which the theoretical concept is evident in everyday experience.

Two methods have been used to determine concept ordering. One method of determining this ordering is by comparing mean scores on tasks by age. Another method is by having each pupil perform a range of tasks and using the results to determine the sequence in which they can be successfully performed (Driver and Easley, 1978, p.65).

It has been suggested by some that the history of scientific ideas, to some extent, reflects a type of psychological ordering of students' explanations of physical phenomena (Driver and Easley, 1978, p.70). However the Aristotelean, Galilean, Newtonian or Einsteinian point of view serve more as a source of ideas than anything else.

The ordering of students' concepts is important in organizing materials for instruction. In addition, it is important to develop teaching strategies which take concept development into account. To this end Walters and Boldt (1970) have proposed the use of 'prescience teaching strategy' (p.176) which is designed to "facilitate transitions from a concrete-perceptual level of understanding to an abstract-conceptual level" (Walters and Boldt, 1970, p.176). Development begins to take place when awareness of "contradiction between thought and experience" occurs (Walters and Boldt, 1970, p.176). A 'transitional teaching strategy' could then be applied according to the need of the student. "It may be (1) that the child needs new information about phenomena or (2) that he needs to utilize information he already has but is unable to assimilate" (Walters and Boldt, 1970, p.177).

In summary, nomothetic and ideographic perspectives are both concerned with the problem of coordinating instructional materials with concept development. However, they both have different emphases. Researchers working from the nomothetic perspective have been primarily interested in determining the ages at which students can handle the logic implicit in science concepts. Researchers working from the ideographic perspective have the additional interest of (a) identifying the alternative ways students interpret phenomena from their own everyday concrete experiences and (b) determining how these alternative frameworks are involved in the students' learning of science concepts.

2.20 LITERATURE IN THE SPECIFIC CONTENT AREA

Students' ability to perform tasks involving concepts of speed and acceleration has received attention from three different perspectives.

(1) Empirical studies documenting the acquisition of these concepts.

(2) Studies identifying alternative frameworks for related concepts.

(3) Studies evaluating logical requirements necessary to understand these concepts.

The first perspective deals with the acquisition of these concepts. Few empirical studies have been carried out in this area. Raven's (1972) use of Piaget's inclined plane experiment is the most significant and has shown that, at least for low rates of acceleration and speeds, many twelve-year-olds interpret acceleration at least as gradually increasing speed. However, in this study the tasks used are relatively simple. For example, since two objects are not used simultaneously, such independent variables as relative position or height on the plane, time of release which determines initial velocity, and mass of the balls are not tested for their effect on the students' interpretation of the motion. Also, in this study low speeds are used throughout. This makes the motion perceptually simple as compared to rapidly-moving objects which become blurred. In addition, there is some evidence that preceding and overtaking are not the only criteria for motion analysis (Morei, Kojima and Deno, 1976). These researchers contend that instantaneous velocity is involved as well in making distance and time inferences.

With respect to the development of concepts of velocity and acceleration, Grass (1972) concluedes that a "ribbon spiral" of concept arrangement exists for motion. He suggests that concepts of motion be introduced repeatedly over a period of several years. In this way a greater degree of understanding of the same types of motion and of more complex forms can be attained in subsequent years. Unfortunately, the details of this suggested sequencing are not provided and have not been tested.

The second perspective is that of the search for alternative frameworks. Here Nussbaum's and Novak's (1976) study illustrates the method well, although it is the only one in this category. In this study children's concepts of the earth were investigated using imaginary free-falling objects. These were located at different points on the earth. The predictions also had to be explained.

> Audiotape recordings of the inverviews and the drawings made by the pupils were analysed in terms of underlying conceptual frameworks. Five such frameworks were identified varying from the flat earth and no concept of extended space to a spherical earth in extended space. Although the study was undertaken with 7-8 year olds, it was reported that all five frameworks had been identified with 12-14 year old pupils.
> (Driver and Easley, 1978, p.78)

The third perspective, the logical requirements involved in understanding accepted concepts, has been researched more extensively. Weinreb and Brainert (1975) conclude that the groupement theory of Piaget seems inappropriate to construct the levels of cognitive development necessary to analyze space and time concepts, while Boulanger (1976) has shown that attempts to train children for the schema of proportional reasoning makes the student distrust his own insights and observations. In fact, Body (1978) concludes that the analysis of logical requirements for tasks as expressed by the requirements of 'formal operations' has been much over-simplified, as this is so difficult to define and the contextual effects are so significant.

2.30 LITERATURE SUGGESTING IMPLICATIONS FOR CURRICULUM AND INSTRUCTION

Alternative frameworks of students present a real problem for the design of curricula and teaching strategies. On the one hand, there is considerable evidence that these frameworks exist and present problems to the student, inspite of standard instruction. On the other hand, some directions have been suggested to deal with the problems presented by alternative frameworks. Some curriculum projects have even been designed which deal specifically with alternative frameworks.

The problem of these alternative frameworks does not simply evaporate if ignored. They tend to resist standard instruction.

> Misconceptions in the areas of dynamics have received particular attention. In a study of high school and university students, Lebouter (1976) identified commonly held

> misconceptions related to ideas of force and motion which persist despite instruction. These have been explored more thoroughly by Viennot (1974) who analysed attempts at solving dynamic problems by university physics students. The results indicate that certain pre-Galilean ideas persist and reappear in sophisticated tasks. (Such as student's attempt to solve problems involving simple harmonic motion or projectile motion).
> (Driver and Easley, 1978, p.67).

In fact, Driver and Easley (1978) suggest there may be some cases in which formal instruction obstructs learning. (Piaget, 1973).

Several solutions have been proposed and a few programs have been implemented to deal with the problem presented by the apparent inability of standard instruction to deal adequately with alternative frameworks.

It is necessary to start from the students' viewpoint in instruction.

> Ausubel, for instance, contends that the child's conceptions can be manipulated, providing the instruction allows the children to anchor new information on relevant specific ideas previously existing in his cognitive structure.
> (Nussbaum and Novak, 1976, p.549)

Informal communication in small groups has been used to facilitate conceptual development (Ten Voorde, 1977). But, the central issue which is involved is a dramatic change "amounting at times to a paradigm shift in pupils' thinking and the conditions which facilitate it" (Driver and Easley, 1978, p.80).

Walters and Boldt (1970, p.177) have outlined a specific teaching strategy appropriate for this transitional process. Its main thrust is to test thought against experience.

> Very often the main impetus for sustained effort of this kind of activity comes from the challenge of matching expectations with nature. Usually this poses all sorts of puzzles that have to be resolved. The solving of these puzzles is often a highly creative undertaking. Through developmental activity of this kind, the learner eventually encounters puzzles which he cannot resolve no matter how hard he tries. If the confrontation becomes serious enough, the puzzle may acquire the force of an anomaly and initiate a new conceptual change.
> (Walters and Boldt, 1970, p.177)

Erickson (1979) has proposed the use of 'anomaly maneuvers' to actively promote uncertainty and change in the students' framework.

> Once students have attained such a set of beliefs another teaching maneuver might involve the creation of a situation that leads to unexpected outcome for the students. Such an *anomaly maneuver* is designed to introduce an element of uncertainty into the student's beliefs, with the expectation that the uncertainty will eventually be resolved with a type of reorganization or restructuring of the child's intuitions and beliefs.
> (Erickson, 1979, p.22)

Following this, a set of 'restructuring maneuvers' were proposed to help in the students' accommodation of outcomes that were unexpected.

Some attempts are being made to actually implement curriculums which take alternative frameworks into account.

One such program is that of Delacôte in France. (Driver and Easley, 1978, p.77). This project involves students between the ages 9-15 years. It is attempting to develop and evaluate a science program which aims to identify the alternative frameworks of students and help them to assimilate theoretical frameworks.

Finally, Brown and Desforges (1977) caution that it is important at this stage in the research not to be too ambitious in developing taxonomies which are too comprehensive. A building process is required.

> The implications for curriculum design are that, initially, we must abandon the search for general structures and set about producing taxonomies of behaviours for specific areas of the curriculum. In the long term, when sufficient taxonomies have been established, we may look again for general structures, but to start, as Piaget does, with a search for such generality has proved to be inappropriate.
> (Brown and Desforges, 1977, p.16)

2.40 SUMMARY

The literature in the general problem area indicates that two perspectives, the nomothetic and the ideographic, have been used in researching the development of science concepts in students.

In the specific area, the problem of the development of students' concepts of motion has not been researched extensively except from the Piagetian framework. Also serious challenges have been levelled against a number of its claims (particularly the groupement theory).

The present study identifies students' beliefs about motion in the context of their intuitions and experience. In this sense it is an ideographic rather than a nomothetic approach to the problem.

The investigation of the students' beliefs about free-fall motion is significant since:

(a) Problems of motion are central to physics.

(b) A variety of alternative frameworks are possible.

(c) Problems of motion show evidence of resistance to standard instruction. (Lebouter, 1976; Viennot, 1974).

It has also been suggested in the literature that alternative frameworks present a real challenge to instruction and curriculum design.

CHAPTER THREE

METHODS OF STUDY

3.00 INTRODUCTION

This chapter will deal with three aspects of the methods used. The section dealing with the interview procedure includes a description of the apparatus and of the training session. The section which describes the tasks gives a detailed account of tasks dealing with a single object in free-fall and tasks involving two objects in free-fall under varying conditions of height, initial velocity and weight. Finally, the section dealing with the subjects describes their selection and the composition of the sample.

3.10 INTERVIEW PROCEDURE

Each interview was conducted using a similar set of procedures. First, a training session was completed to ensure that the subjects understood the operation of the equipment. Second, the same set of three tasks was administered to each subject.

These interviews were conducted during the months of March and April, 1979. They were conducted immediately after school in a room with only the student and the interviewer present. Each interview was recorded using a cassette tape recorder. Normally,only one interview was conducted on any day. A transcript was made of each interview on the same day it was conducted.

The interviews were conducted in the following order. First,the grade 10 students; then,the grade 11 students; then,the grade 8 students; and, finally, the grade 6 students were interviewed. These interviews took an average of about thirty minutes. The last interviews with the grade 6 students tended to be a little shorter, having an average length of about twenty minutes. All interviews used the same tasks,but fewer follow-up questions tended to be required for the grade 6 students.

3.11 The Apparatus

The apparatus shown in Figure 3.1 was set up and used in the interviews. It was chosen for its novelty as well as for its accuracy.

Generally, few problems were encountered in the interviews. The students did not appear to be intimidated by the apparatus and, in fact, the use of photocells and a digital timer created interest because of their novelty.

The hundredths and thousandths decades of the digital counter were covered with opaque electrical tape. As a result, only the tens, units and tenths decades could be read.

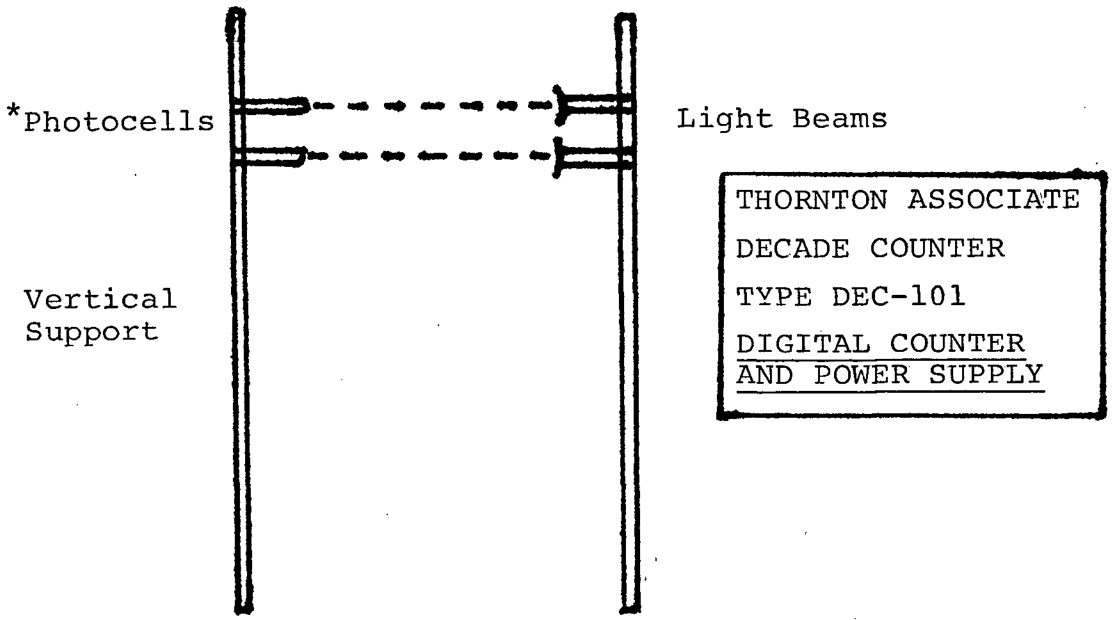

Figure 3.1

The Apparatus

This degree of accuracy in the timer was considered to be precise without being confusing. The counter was started when the light beam at the top was interrupted. It was stopped when the beam at the bottom was interrupted. Thus, the time of transit of an object moving through the gap between the first and second photocells was measured as it successively interrupted first the top and then the bottom beam on its way through the gap.

The sources and photocells were attached to coloured clothespins. They, therefore, could be clipped onto any position on the metre sticks. As a result, a gap of any size at any

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*The photocells were clipped on and moveable. The top one was attached to a blue clothespin. and the bottom one to a red clothespin.

location could easily be set up. The blue clothespins were at the top of the gap and the red clothspins were at the bottom. Additional blue and red clothespins were provided so that positions of a series of gaps could be simulated and remain on the metre sticks.

Three shotputs were used. Two identical red ones weighed 4 kg. One heavier yellow shotput weighed 6 kg.

3.12 Training Session

The training session both acquainted the student with the apparatus and enabled the investigator to determine whether they understood its operation. At first the investigator moved his hand through the gap to show the student how the digital counter registered time. Then the student was instructed to start and stop the timer in a similar way with their hand for a gap of ten centimetres distance between the light beams.

The following procedure was used:

I. - Interviewer ; S. - Subject

I. - "Would you start and stop the timer the way I did. Move your hand fairly slowly."

S. - The student performed this action.

I. - "How long did that take?"

S. - The student read the digital timer.

I. - "Now would you do the same thing but move your hand a little faster."

S. - The student performed the action.

I. - "How long did that take?"

S. - The student read the timer.

I. - "Now, would you move your hand through even faster than that."

S. - The student performed the action.

I. - "How long did it take this time?"

S. - The student read the timer.

I. - "Now, would you explain how the speed of your hand is related to the reading on the timer."

The interview did not proceed until the student clearly indicated that for a fixed gap the time of transit was decreased as the speed of the hand was increased. It was also to be indicated that for a gap twice the size the speed would have to be increased to register the same time of transit as for the smaller gap. Follow-up questions were used if necessary, but no significant problems occurred.

3.20 THE TASKS

The tasks were designed to test the following:

(a) The student's beliefs about the motion of a single object in free-fall (tasks 3.21, 3.22).

(b) The student's beliefs about the effect of height (task 3.23A), initial velocity (task 3.24A, 3.25A) frame of reference (tasks 3.23A, 3.24B, 3.25B) and weight (tasks 3.26A, 3.26B) on the motion of an object in free-fall.

(c) The student's beliefs about the combined action of the variables of height and initial velocity (tasks 3.24A, 3.24B, 3.25A, 3.25B), height and weight (tasks 3.26A, 3.26B), and initial velocity and weight (3.27, 3.28).

3.21 A Single Object in Free-Fall

A gap of 10 cm was set between the photocells which were pinned respectively at the zero centimetre and ten centimetre positions. One of the 4 Kg indoor shotputs was held in position immediately above the first photocell and dropped through the gap. This drop was timed and the student was first requested to read the time for the fall. In this case the timer read one-tenth of a second on all occasions. (This was the only experiment actually done. All the remaining tasks were done as thought problems). The following instructions were then given.

> The shotput which was dropped from zero continued its fall past the 10 cm mark. Suppose that we had placed the first photocell mounted on the blue clothespin at the 50 cm mark. This one, you remember starts the timer. (This clothespin was then pinned at the 50 cm mark). Now, the shotput which started at zero cm would fall for 50 cm and then start the timer. The second photocell mounted on the red clothespin stops the timer. Where would you place this second photocell so that the timer would read one-tenth of a second?

After their positioning of the lower photocell, the student was asked to explain their reasons for choosing that particular location.

The student was asked to compare the speed of the shotput in the gap from zero cm to 10 cm and the speed in the gap starting at 50 cm. This was done to check the meaning of the student's prediction. If the predicted gap was the same size (10 cm), this should have indicated that the speed was judged to be constant. If the predicted gap was larger than 10 cm, this should have indicated that the speed was judged to increase or accelerate.

This procedure was repeated for different intervals in the path of the free-falling shotput. The student was asked to construct appropriate gaps starting successively at the 100 cm, 150 cm, and 200 cm marks. Additional blue and red clothspins were used by the students to mark successive gaps. In this way previously marked gaps could remain on the scale as a continuous record.

The student was asked, in addition, what would happen to the speed of the shotput if it was able to fall further before hitting the ground. Again, not only a prediction, but also an explanation was requested.

3.22 Average Speed Task

Only those students who indicated that some form of acceleration was occurring proceeded to the next part of the task. This task indicated whether the student believed that velocity varies with displacement or with elapsed time.

The student's attention was directed to the designated gap starting at the 100 cm mark. For this gap the following three locations were to be indicated:

a) "At what point in this gap was the shotput going the slowest speed?"

All of the students then pointed to the blue clothespin.

b) "At what point in this gap was the shotput going the fastest speed?"

All of the students then pointed to the red clothespin.

c) "At what point in this gap was the shotput going at a speed which was one-half way between the slowest speed and the fastest speed?"

3.23A <u>The Factor of Height - External Earth Frame</u>

The effect of a height difference between two shotputs was tested in this task. One shotput was held by the interviewer at the zero cm mark while the student held the second identical shotput at the 25 cm mark. He was given the following problem.

I - "How big is the gap between the shotputs?"

S - 25 cm.

I - "Suppose I counted one, two, three, go, and on the word 'go' you dropped your shotput and I dropped my identical shotput at exactly the same time. Can you describe the gap between the two shotputs as they fall down?"

If they indicated that the top one would begin to overtake the bottom one, some additional questions were used to make this precise.

I - "Does the top one catch the bottom one?"

S - (If yes)

I - "Does it pass?"

S - "What happens to the gap between them after that?"

Additional explanations were sought with the question:

I - "Please explain why you think that (the prediction) would happen?"

3.24A <u>The Factor of Initial Velocity - External Earth Frame with Initial Separation</u>

The effect of time separation or the advantage of an initial velocity was tested in this task. Again, the same two identical shotputs were used.

One shotput was held by the interviewer at the zero cm mark while the student held the second shotput at the 100 cm mark. The following problem was given:

I - "Suppose that I counted one, two, three, go, and dropped my shotput, but you waited; you did not drop yours at the same time. Suppose you waited until mine had fallen till it was at the 40 cm mark. (The shotput was positioned at that point). Just when it reached that 40 cm mark you dropped yours. After that they both would be falling. How far apart are they just as you drop your shotput?"

S - "60 cm (between 40 cm and 100 cm)"

I - "Would you describe the gap between the two as they fall further?"

S - (If it is described as getting smaller due to the initial velocity of the top shotput, the next questions are asked).

I - "Does the top one catch up to the bottom one?"

S - (If the answer is yes...)

I - "Does it pass?"

S - (If the answer is yes...)

I - "Then what happens?"

S - ......

I - "Can you explain your answer?"

S - (Gives an explanation, if possible).

3.25A <u>The Factor of Initial Velocity - External Earth Frame with Shotputs Initially Even</u>

The effect of time separation or the advantage of an initial velocity was again tested in this case. It was very much the same as in 3.24A except with the second shotput waiting at the 100 cm mark while the first shotput was dropped from the zero cm mark. However, in this case, the effect of an initial velocity was more sharply accentuated. The top one was described as dropping until it was even with the bottom one at the 100 cm mark before the later one was released. This was demonstrated by positioning the shotputs according to the description. The following questions were asked.

I - "Where is the other shotput just as you drop yours?"

S - "Just beside mine."

I - "Can you compare their positions just after you drop yours?"

S - (If the top one is described as passing the bottom one?

I - "Can you describe the gap between the two as they fall further?"

S - ....

I - "Why does this happen?"

S - (Gives an explanation, if possible)

3.23B, 3.24B, 3.25B <u>Internal Frame</u>

At this point in the interview tasks 3.23A, 3.24A, and 3.25A were repeated exactly, but with a change in the frame of reference. In the 'A' form the frame was external to the shotputs. It was an earth frame, the frame of the student. To test the student's ability to shift frames of reference, a common problem in kinematics, the 'B' form of the tasks used an internal frame attached to the lower shotput.

The student was to imagine taking a sitting position on the lower shotput, riding it down as it fell and observing the ball above. This presence would not change any action. The student was only an observer. The problem was to describe observations made from that internal frame.

The consistency of these descriptions with those given from the earth frame were noted.

3.26A and 3.26B <u>The Factor of Weight Versus the Factor of Height</u>

These two tasks were a repeat of task3.23A with one difference - the two shotputs were not identical in weight. The variables of weight and height were pitted against each other in the 'A' and 'B' forms of this task. One red 4 kg shotput was used with one yellow 6 kg shotput. The student was required to handle them to verify this difference in weight.

In 3.26A the 4 kg shotput was on top and the 6 kg shotput was on the bottom.

In 3.26B the 6 kg was on top and the 4 kg shotput was on the bottom.

3.27 <u>The factor of Weight Versus The Factor of Initial Velocity - Initial Separation</u>

This task was a repetition of task 3.24A again with the same difference of weight in the shotputs. Weight and initial velocity were pitted against each other using the 4 kg shotput on the top and the 6 kg shotput on the bottom. The height could also have been considered as a variable.

3.28 The Factor of Weight Versus The Factor of Initial Velocity - Shotputs Initially Even

This task was a repeat of 3.25A again with the same difference of weight in the shotputs. Again, weight and initial velocity were pitted against each other, but the initial velocity is accentuated by allowing the top shotput to draw alongside the bottom one.

3.29 Additions

After the interview was completed, the student was invited to add any further comments or information. In many cases the students wished to discuss the tasks. They wanted to know what the 'right' answers were.

3.30 SUBJECTS

Six students were interviewed at four different grade levels, making a total of twenty-four subjects. These were selected from grade 6, grade 8, grade 10 and grade 11 students, respectively. Each sample of six students from each grade was composed of three girls and three boys. These subjects were randomly selected from a given class of students by choosing names from subgroups of boys' and girls' names written on slips of paper.

The grade 6 students were selected out of an average class of students from a North Vancouver elementary school.

The grade 8, grade 10 and grade 11 students were selected out of science classes from a North Vancouver secondary school. All of the grade 8 and grade 10 students were selected from general science classes. General science is a required course for all grade 8 and 10 students.

Six grade 11 students were chosen from a Physics 11 class. This is an elective academic course. This group had just completed section four (Motion in One Dimension) in A Laboratory Course in Physics. This group, therefore, had completed instruction in kinematics and were assumed to have competence in applying the normal kinematics equation, graphs, and to understand the constant value of 'g', the acceleration due to gravity. This grade 11 group was included to determine if there are any significant differences in the response patterned to those students who had not received formal instruction in kinematics.

CHAPTER FOUR

RESULTS

4.00 INTRODUCTION

This chapter deals with the methods of analysis and results of the investigation.

A Methods of Analysis section details the interpretation and classification of the responses task by task. Subtask responses are considered within the three major tasks dealing with the characteristics of free-fall motion, the relevance and behaviour of independent variables affecting the motion, and the combined effect of the independent variables.

A Results section first details the responses under the same three major tasks mentioned above. A table of frequencies of responses within defined categories is given for each of the three major tasks. This table gives frequencies of responses by grade, by grade and sex, and by sex. The grade 11 physics group is also considered as a treatment by instruction group. Typical responses are quoted to illustrate the classification system. Trends within the data are then noted.

Following this, the Results section details the general trends when all three major tasks are considered together. Then, an explanation section uses quotations to illustrate the sources cited by the students for their beliefs.

Finally, there is a discussion of a few cases in the grade 11 group in which changes of mind occurred.

4.10 METHODS OF ANALYSIS

This section details the methods used to classify the responses for the tasks described in Sections 3.21 through 3.28. The terms used for response categories are also used in the data tables which appear in the Results section which follows.

4.11 The Characteristics of Motion of a Single Shotput in Free-Fall (Table 4.1)

The characteristics of motion for a single shotput in free-fall were studied (tasks 3.21, 3.22).

The following four response categories were derived from analysing the transcripts (task 3.21):

1) Constant velocity - The speed of the object was constant from beginning to end.

2) Acceleration as an impulse - The speed of the object was increasing in a short impulse* only in the first 10 cm to a constant speed.

3) Acceleration to a terminal velocity - The acceleration decreased in rate such that a final constant or terminal velocity was achieved.

4) Acceleration as a continuous action - The acceleration was uniform without being qualified.

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*The word impulse will be used to indicate action as a burst over a short time interval.

Only those students who indicated that some form of acceleration was taking place proceeded to the next part of task 3.22. In that case two response categories were evident:

1) Acceleration as a continuous action - Speed varied with displacement. The point at which the half-way speed occurred was the exact midpoint of the gap.

2) Acceleration as a continuous action - speed varies with elapsed time - A location other than the mid-point was chosen. An appropriate explanation for this choice was given.

4.12 <u>The Relevance of Other Factors</u>

The relevance of the variables of height, initial velocity and weight were studied (tasks 3.23 through 3.28).

4.121 <u>The Relevance of Height as an Independent Variable Affecting Free-Fall Motion</u> (Table 4.2)

The following four response categories were derived from analysing the transcripts for the factor of height (tasks 3.23A, 3.23B).

1) Height is not a factor - The gap between the two shotputs remained a constant value of 25 cm as they fell.

2) Height operates only in an impulse mode - The top shotput gained only a short distance on the bottom one and no more after that.

3) Height operates, but dissipates in effect - The top shotput at least overtook the bottom one or passed it and then remained a fixed distance ahead.

4) Height operates as a continuous action - The top shotput overtook the bottom one, passed it and then continued to increase its separation.

4.122 <u>The Relevance of Initial Velocity As An Independent Variable Affecting Free-Fall Motion (Table 4.3)</u>

The following four response categories were derived from analysing the transcripts for the factor of initial velocity (tasks 3.24A, 3.25A, 3.24B, 3.25B0).

1) Initial velocity is not a factor.

- The initial separation of 60 cm in the delayed drop (task 3.24A, 3.24B) doesn't decrease as they fall.

- They start even at the 100 cm mark in the second delayed drop. They remain even all the way down (task 3.25A, 3.25B).

2) Initial velocity operates only in an impulse mode.

- In the first delayed drop the initial separation of 60 cm is reduced only a very little and subsequently remains constant (tasks 3.24A, 3.24B).

- In the second delayed drop they start even at the 100 cm mark. The one that was dropped first gains only a few cm then remains a fixed distance ahead or even loses its advantage (tasks 3.25A, 3.25B).

3) Initial velocity operates but dissipates in its effect.

- In the first delayed drop the initial separation of 60 cm is reduced. The one that was dropped first at least overtakes the bottom one, possibly even passes it, but subsequently remains a fixed distance ahead (tasks 3.24A, 3.24B).

- In the second delayed drop they start even at the 100 cm mark. The one that was dropped first passes the bottom one and then attains a substantial separation which subsequently remains constant (tasks 3.25A, 3.25B).

4) Initial velocity operates as a continuous action.

- In the first delayed drop the initial separation of 60 cm is reduced. The one that was dropped first overtakes, passes and continues to increase its separation from the second one (tasks 3.24A, 3.24B).

In the second delayed drop they start even at the 100 cm mark. The one that was dropped first passes the second one and continues to increase its separation from the second one (tasks 3.25A, 3.25B).

4.123 The Relevance of Weight as an Independent Variable Affecting Free-Fall Motion (Table 4.4)

The following four response categories were derived from analysing the transcripts for the factor of weight (tasks 3.26A,3.26B).

1) Weight is not a factor.

- If two shotputs of unequal weight are separated by a difference in height and dropped simultaneously, the result is the same whether the lighter one is on top (task 3.26A) or the heavier one is on the top (task 3.26B).

2) Weight operates only in a short impulse mode.

- The heavier shotput gains a few centimetres and no more on the lighter one (task 3.26A, 3.26B).

3) Weight operates, but dissipates in its effect.

- If it is lower, the heavier one gains a substantial distance on the lighter one. This distance of separation subsequently remains a constant value (task 3.26A). If the heavier one is higher, it at least catches the lighter one, passes it and subsequently remains a fixed distance ahead (task 3.26B).

4) Weight operates as a continuous action.

- If the heavier one is on the bottom its separation from the lighter one continues to increase (task 3.26A). If the heavier one is higher, it catches the lighter one, passes it and its separation from the lighter one continues to increase.

4.130 The Combined Effect of Variables

The study also attempted to isolate the combined effect of the variables of height, weight and initial velocity.

Each of the possible combinations of variables had a number of logical possibilities. These were the following:

1) Neither of the variables act.

2) Only the first variable in a combination acts.

3) Only the second variable in a combination acts.

4) Two variables both act, but the first one was more important than the second one. Its effect was stronger.

5) Two variables both act with equal strength or importance.

6) Two variables both act, but the second one was more important or stronger than the first one.

4.131 <u>The combined Effect of the Independent Variables Height and Weight</u> (Table 4.5)

The following six response categories were evident:

1) Neither one is applied.

   - The initial height separation of 25 cm between shotputs of different weight remains constant when dropped simultaneously no matter which one is higher (task 3.26A, 3.26B).

2) Height only is applied.

   The 25 cm height difference decreases in the same way for two shotputs of different weight no matter which one is on top (task 3.26A, 3.26B).

3) Weight only is applied.

   - The 25 cm height difference increased immediately when the heavier one is at the bottom (task 3.26A). It decreases immediately when the heavier one is at the top (task 3.26B).

4) The effects of height and weight are of the same importance.

   - The 25 cm height difference remains constant when the heavier one is at the bottom (task 3.26A). It decreases rapidly when the heavier one is at the top (task 3.26B).

5) The effect of height is more important than the effect of weight.

- The 25 cm height difference decreases when the heavier one is at the bottom (task 3.26A). It decreases much faster when the heavier one is at the top (task 3.26B).

6) The effect of weight is more important than the effect of height.

- The 25 cm height difference increases when the heavier one is at the bottom (task 3.26A). It overtakes the bottom one at a faster rate when the heavier one is at the top.

4.132 <u>The Combined Effect of the Independent Variables Initial Velocity and Weight</u> (Table 4.6).

The following six response categories were evident.

1) Neither one is applied.

- If the initial separation was 60 cm in the first delayed drop with shotputs of different weight (task 3.27) the separation remained at that value.

- If they were even at the 100 cm mark in the second delayed drop with shotputs of different weight (task 3.28) they remained even the rest of the way down.

2) Initial velocity only is applied.

- In the same first delayed drop the initial separation of 60 cm decreased with time (task 3.27).

- In the second delayed drop where they were even at the 100 cm mark (task 3.28) the one that was dropped first passed the second heavier one.

- The predictions in both of the tasks above was the same as the predictions for the equivalent tasks in which there was no weight difference (tasks 3.24, 3.25).

3) Weight only is applied.

- In the same first delayed drop if the initial separation of the shotputs was 60 cm (task 3.27) this separation began to increase as soon as the lower heavier shotput was released.

- In the same second delayed drop if the two shotputs were even at the 100 cm mark (task 3.28), the lower heavier one immediately began to gain distance on the one that was dropped first.

4) Initial velocity is equal in effect to weight.

   - In the same first delayed drop if the initial separation of the shotputs was 60 cm (task 3.27), the gap remained the same from the beginning or shortly thereafter.

   - In the same second delayed drop if the two shotputs were even at the 100 cm mark (task 3.28), the top lighter one passed the bottom one. The gap between the two either remained constant or the heavier one overtook the lighter one, and then they remained even for the rest of the fall.

5) Weight has a greater effect than initial velocity.

   - In the same second delayed drop if the two shotputs were even at the 100 cm mark (task 3.28), the top lighter shotput first passed the bottom one. After this, the heavier one overtook the lighter one, passed it and continue to have the advantage of a faster speed or acceleration.

6) Initial velocity has a greater effect than weight.

   - In the same second delayed drop if the two shotputs were even at the 100 cm mark (task 3.28), the heavier shotput receded behind the lighter one which had the advantage of an initial velocity.

4.133 <u>The Combined Effect of the Independent Variables Height and Initial Velocity</u>

The following four of the six possible response categories were evident:

1) Neither one is applied.

   - In the first delayed drop with shotputs of equal weight the initial separation (between the top and bottom shotputs) was 60 cm. This separation remained the same size as they fell.

2) Height only is applied.

   - In the task involving the simultaneous drop of two shotputs of equal weight (task 3.23) there was an initial separation of 25 cm. A height advantage is applied. No additional advantage is given to the top shotput if it is dropped first (task 3.24, 3.25).

3) Initial velocity only is applied.

   - The top shotput has no advantage in the simultaneous drop of two shotputs of equal weight with a 25 cm height separation (task 3.23A, 3.23B). However, the top one does have an advantage in the delayed drop (task 3.24A, 3.24B).

4) Initial velocity and height effects add.

   - Height is an advantage for the top shotput in the simultaneous drop with an initial height difference (task 3.24A, 3.23B). Height and initial velocity are described as a double advantage for the top shotput. These add together for the top shotput when the bottom one is delayed (task 3.24, 3.25).

4.20 RESULTS

This section has three subsection which refer back to the three corresponding Sections 4.11, 4.12 and 4.13, respectively. In each case a table of results is given, typical responses are quoted to illustrate the classification system clearly and trends within the data are delineated.

In addition, Section 4.24 delineates the overall trends within the data and Section 4.25 details the origins of the beliefs detailed.

Table 4.1

The Characteristics of Motion of a Single Shotput in Free-Fall
(From Tasks 3.21 and 3.22)

Group	Constant Velocity	Acceleration as an Impulse	Acceleration to a Terminal Velocity	Acceleration as a Continuous Action Speed Varies With Displacement	Acceleration as a Continuous Action Speed Varies with Elapsed Time
TOTALS BY GRADE					
Grade 6	3	0	0	3	0
Grade 8	0	1	2	1	2
Grade 10	1	1	2	1	1
*Grade 11	0	0	0	4	2
Totals	4	2	4	9	5
TOTALS BY SEX					
Girls	2	0	0	6	4
Boys	2	2	4	3	1
Totals	4	2	4	9	5
TOTALS BY SEX AND GRADE					
GIRLS					
Grade 6	1	0	0	2	0
Grade 8	0	0	0	1	2
Grade 10	1	0	0	1	1
Grade 11	0	0	0	2	1
BOYS					
Grade 6	2	0	0	1	0
Grade 8	0	1	2	0	0
Grade 10	0	1	2	0	0
Grade 11	0	0	0	2	1
Totals	4	2	4	9	5

*Instruction Group

4.212 Typical Responses

The quotations cited are accompanied by the classifications assigned to them as well as other pertinent information.

I. - Interviewer ; S. - Subject

1) CLASSIFICATION - Constant velocity, no acceleration.

Subject - L. a grade 6 girl.

Gaps Marked by the Subject - (50-60); (100-110); (150-160); (200-210).

Quotation - For task 3.21:

I. - "Why did you place the pegs that way?"

S. - "'Cause if it's 10 cm at the top it would still fall the same coming down."

I. - "How do the speeds in the gaps compare?"

S. - "They're the same."

I. - "All the way down?"

S. - "Yes."

2) CLASSIFICATION - Acceleration as a short impulse.

Subject - P.G. a grade 8 boy.

Gaps marked by the Subject - (50-60); (100-110); (150-160); (200-210).

Quotations - (For 3.21:)

I. - "Why did you indicate the gaps in that way?"

S. - "Because up at the top they were 10 cm apart so down below they should be the same."

I. - "Why do you think so?"

S. - "Objects move pretty much the same speed going down."

In task 3.25 a short impulse of acceleration is described.

S. - "*Yours would go a little bit further because mine would have to start up.*"

I. - "Would it pass?"

S. - "It would pass a couple of centimetres and then stay the same."

3) CLASSIFICATION - Acceleration which dissipated to a terminal velocity.

Subject - L.W. a grade 10 boy.

Gaps Marked by the Subject - (50-65); (100-140); (150-200); (200-260).

Quotation - For task 3.21

I. - "What would happen if the shotput could fall further?"

S. - "The ball would gain speed up to a certain point and then, ultimately, because of the force of gravity, it can't go any faster. It is only so strong ... It (gravity) will allow it (the shotput) to go to a certain speed and will stay the same for the rest of its fall."

4) CLASSIFICATION - Acceleration in a continuous manner.

Subject - K.C. a grade lo girl.

Gaps Marked by the Subject - (950-64); (100-120); (150-178); (200-further).

Quotations - For task 3.21

I. - "Why did you put the clothespegs further apart?"

S. - "'Cause the ball is going faster. Probably it gained momentum as it comes down."

I. - "What would happen if it could fall further?"

S. - "The speed of the ball would be increasing, and the distance would be increasing."

5) CLASSIFICATION - Speed varies directly with displacement.

Subject - D.C. a grade 11 boy.

Position Marked in Second Gap - In a gap running from 100 to 200 the 150 cm point was chosen for the occurrence of the halfway speed.

Quotations - For task 3.21 in reference to the second gap.

S. - "It's going five times as fast there (points to 50) so that means it will be five times the distance."

For task 3.22.

I. - "At what point in the gap will the speed occur which is halfway between the fast speed and the slowest speed?"

S. - "150 cm."

I. - "Why?"

S. - "Half the distance; half the speed."

6) CLASSIFICATION - Speed varies with elapsed time.

Subject - K.K. a grade 8 girl.

Position Marked in Second Gap - In a gap running from 100 to 112 cm a point in the first half of the gap was chosen.

Quotation - For task 3.22

I. - "At which point is it going at a speed halfway between the fastest and slowest speeds in the gap?"

S. - "Just before half of the number. Like there's twelve centimetres here (points), so maybe it would be five."

I. - "Why is that?"

S. - "Because as it's picking up speed, it doesn't take as much time...

so it would... It's not going the same speed all the way down,so you couldn't say in the middle it's just halfway... It's hard to explain."

4.213 <u>Trends in the Data for the Characteristics of Acceleration</u>

The following trends are evident in the results:

1) Only three of the grade 6 students applied acceleration.

2) All other students applied acceleration with the exception of the grade ten student.

3) The three grade 6 students who applied acceleration did not qualify it in any way. It was simply a continuous action.

4) No girls at any level qualified acceleration as reaching a terminal velocity or as operating in the form of a short impulse.

5) Six boys in grade 8 and 10 qualified acceleration as having a terminal velocity or as operating in the form of a short impulse.

6) In the grade 11 instruction group acceleration was treated by all students as having a continuous form of action.

7) No grade 6 students considered that speed varied with elapsed time. Those who accepted acceleration considered that speed varied with displacement.

8) The velocity varies with displacement interpretation of acceleration occurred at all grade levels, even in the grade eleven treatment group.

4.2212 Typical Responses - The Effect of Height

1) CLASSIFICATION - Height is not a relevant factor.

Subject - S. a grade 6 boy.

Quotation - For task 3.23A

Table 4.2

The Relevance of Height as an Independent Variable Affecting Free-Fall Motion
(From Tasks 3.23A and 3.23B)

Group	Is not A Factor	Operates Only in An Impulse	Operates But Dissipates In Its Effect	Operates As A Continuous Action
TOTALS BY GRADE				
Grade 6	5	1	0	0
Grade 8	3	0	1	2
Grade 10	2	0	3	1
*Grade 11	4	0	2	0
TOTALS	4	0	2	0
TOTALS BY SEX				
GIRLS	4	1	4	3
BOYS	10	0	2	0
TOTALS	14	1	6	3
TOTALS BY SEX AND GRADE				
GIRLS				
Grade 6	2	1	0	0
Grade 8	1	0	0	2
Grade 10	0	0	2	1
Grade 11	1	0	2	0
BOYS				
Grade 6	3	0	0	0
Grade 8	2	0	1	0
Grade 10	2	0	1	0
Grade 11	3	0	0	0
TOTALS	14	1	6	3

*Instruction Group

I. - "Could you describe the gap between the two as they fall?"

S. - "Let's see. It's 25 at the top,so it'd keep 25 cm as it fell."

I. - "Would it stay 25?"

S. - "Yes"

I. - "Why?"

S. - "One was dropped lower than the other,and they're the same weight,and they get going at the same time".

2) CLASSIFICATION - Height is a factor which operates only as an impulse.

Subject - S.G. a grade 6 girl.

Quotations - For task 3.23A:

S. - "Well, they might come closer together as they come to the ground. The space will become shorter."

I. - "Will it catch up?"

S. - "Not all the way?"

For task 3.23B:

S. - "The ball will probably come closer...the top one and stay the same."

3) CLASSIFICATION - Height as a factor dissipates slowly in its effect.

Subject - P.M. a grade 8 boy.

Quotation - For task 3.23A

S. - "I think that one, the one on the top, would go faster because it has more room. Like this one (points to the bottom one) has less. You started it lower. This one (points to the top one) has more of a chance, because it has more space between this one and that ... and that one. So it has... This one (points to the top one) uses up this far (indicates the 25 cm gap) to catch up that amount (height). So this one (top) already did this, and it already has faster speed by the time it reaches this part (points to the 25 cm mark), and this one (bottom) still is slower from when you release it."

I. - "Would it catch the bottom one?"

S. - "It would catch it just a little lower than where you released this one (bottom)."

I. - "About where would this happen?"

S. - "40 cm."

I. - "Would it pass?"

S. - "The top one would hit the ground first."

I. - "What would the separation between them be?"

S. - "There won't be much of a gap near the end. It would stay the same. It (lower one) might catch up again. No. That one, the one that was at the top would win."

I. - "What would happen to the gap between them after the top one passed?"

S. - "It would stay the same or get less again."

4) CLASSIFICATION - Height as a factor acts in a continuous mode.

Subject - S.S. a grade 8 girl.

Quotations - For task 3.23A:

S. - "I think that if they're dropped over a greater distance, the one that's got more height would gain more speed and catch up."

I. - "Will it pass?"

S. - "It will probably pass."

I. - "Why?"

S. - "Because it's (bottom) still gaining speed all the time, but not at the same rate."

For task 3.23B:

I. - "What would you see as you looked up?"

S. - "This great ball speeding towards you and slowly catching up with you... It would leave you behind."

4.2213 Trends in the Data for the Significance of Height

The following trends are evident in the results:

1) In all cases additional height was either an advantage or was not a factor at all. It never was considered to be a disadvantage.

2) Five of the six grade 6 students did not apply the variable. The one girl who did apply it considered that it acted as a short impulse only.

3) Eight of the twelve girls applied the factor of height in some form.

4) Ten of the twelve boys did not apply it in any form. The two who did apply it considered that it dissipated in effect.

5) Two of the three grade eleven physics girls still applied the factor of height in a dissipating form of action.

6) No physics 11 boys applied the factor in any form.

4.2222 Typical Response - The Effect of Initial Velocity

1) CLASSIFICATION - Initial velocity is not considered.

Subject - L. a grade 6 girl.

Quotations - For task 3.24A:

I. - "How far apart are they at the beginning?"

S. - "60 cm apart."

Table 4.3

The Relevance of Initial Velocity As An Independent Variable Affecting Free-Fall Motion
(From Tasks 3.24A, 3.24B, 3.25A, and 3.25B)

Group	Is Not A Factor	Operates Only In An Impulse Mode	Operates But Dissipates in Its Effect	Operates As A Continuous Action
TOTALS BY GRADE				
Grade 6	3	2	0	1
Grade 8	0	1	2	3
Grade 10	1	1	3	1
*Grade 11	0	0	3	3
TOTALS	4	4	8	8
TOTALS BY SEX				
GIRLS	2	2	3	5
BOYS	2	2	5	3
TOTALS	4	4	8	8
TOTALS BY SEX AND GRADE				
GIRLS				
Grade 6	1	2	0	0
Grade 8	0	0	0	3
Grade 10	1	0	1	1
Grade 11	0	0	2	1
BOYS				
Grade 6	2	0	0	1
Grade 8	0	1	2	0
Grade 10	0	1	2	0
Grade 11	0	0	1	2
TOTALS	4	4	8	8

*Instruction Group

I. - "What happens to this gap as they both fall?"

S. - "They would be 60 cm apart."

For task 3.24B:

I. - "What would you see?"

S. - "A red ball falling 60 cm on top of me."

For task 3.25A:

S. - "They drop at the same time and hit the floor together."

I. - "Do they stay together all the way?"

S. - "Yes."

For task 3.25B:

S. - "I'd see a ball beside me as I'm going down."

2) CLASSIFICATION - Initial velocity operates as a short impulse only.

Subject - P.G. a grade 8 boy.

Quotations - For task 3.24A:

S. - "Yours would go little bit further, because mine would have to start up."

I. - "Would it pass?"

S. - "It would pass a couple of centimetres and then stay the same."

3) CLASSIFICATION - Initial velocity operates but with a slowly dissipating effect.

Subject - P.M. a grade 8 boy.

Quotations - For task 3.25A:

S. - "It passes, goes to a certain point ahead and stays that far ahead."

I. - "Why does that happen?"

S. - "The first one's already going, so it passes the second one. Then, the second one starts and the space is already there where ... where it's already going in the first place (100 cm) ... and that after the second one goes, the gravity is the same on both of them and just so they go down at the same rate. So, the space stays the same."

For task 3.25B:

S. - "I'd see it go past me, and then it'd follow, and then I'd be following it. Because the distance between us... It would be going down at the same velocity after a while."

4) CLASSIFICATION - Initial velocity operates in a continuous manner.

Subject - K.C. a grade 10 girl.

Quotations - For task 3.24A

S. - "The first one (top) would have a little more of a chance to go faster, so maybe (pause) this one (top) would catch up a little bit. I guess maybe it'll ... Yeah! I guess it should just keep catching up and pass the other one (lower) ... The distance between them would increase."

I. - "Why would this happen?"

S. - "Because if this one (top) is going faster when it's falling and so ... because it has that distance (40 cm separation) at first, the distance between 40 cm and 100 cm... It's going to have that extra little push in the beginning, and it will keep going."

4.2223 <u>Trends in the Data for the Significance of Initial Velocity</u>

The following trends are evident in the results:

1) This factor was not applied by 3 grade 6 students. Two additional students only applied the factor as a short impulse, while one boy applied it in a continuous manner.

2) The factor was applied to some extent by all the rest of the students except by one grade 10 girl.

3) Of the twenty students who applied the factor, only eight considered it to provide a continuous advantage. Only one of these eight was a grade 6 student.

4) Three of the grade 11 students still believed that the advantage provided by an initial velocity slowly dissipated.

4.2232 Typical Responses - The Effect of Weight

1) CLASSIFICATION - Weight is not relevant.

Subject - L. a grade 6 girl.

Quotations - For task 3.26A:

S. - "They should stay the same."

I. - "Why?"

S. - "They stay the same because the pull of gravity is the same as ... the same whether an object's heavier or lighter."

For task 3.26B:

S. - "It would be 25 cm apart (as they fell)."

I. - "All the way down?"

S. - "Yes, all the way down."

2) No cases occurred in which weight was described as operating in an impulse made of action.

3) CLASSIFICATION - Weight dissipates as a factor.

Subject - K.S. a grade 6 boy.

Quotations - For task 3.26B:

I. - "Would the top one catch up?"

S. - "Maybe ... if it could fall a long way ... I guess so."

I. - "Would it pass?"

S. - "No."

I. - "Why not?"

S. - "I don't know. They would probably just catch up ... and stay even."

Table 4.4

The Relevance of Weight As An Independent Variable Affecting Free-Fall Motion
(From Tasks 3.26A and 3.26B)

Group	Is Not A Factor	Operates Only In An Impulse Mode	Operates But Dissipates In Its Effect	Operates As A Continuous Action
TOTALS BY GRADE				
Grade 6	1	0	0	5
Grade 8	2	0	0	4
Grade 10	1	0	1	4
*Grade 11	1	0	0	5
TOTALS	5	0	1	18
TOTALS BY SEX				
GIRLS	2	0	1	9
BOYS	3	0	0	9
TOTALS	5	0	1	18
TOTALS BY SEX AND GRADE				
GIRLS				
Grade 6	1	0	0	2
Grade 8	1	0	0	2
Grade 10	0	0	1	2
Grade 11	0	0	0	3
BOYS				
Grade 6	0	0	0	3
Grade 8	1	0	0	2
Grade 10	1	0	0	2
Grade 11	1	0	0	2
TOTALS	5	0	1	18

*Instruction Group

4) CLASSIFICATION - Weight operates in a continuous manner.

Subject - L. a grade 11 girl.

Quotations - For task 3.26A:

I. - "What happens to the distance between them?"

S. - "It spreads apart. That one (top) goes slower and this one (bottom) goes faster than that one."

I. - "Do they keep spreading apart?"

S. - "I guess so."

I. - "Why?"

S. - "This one is heavier so it falls faster than that one."

4.2233 Trends In The Data For The Significance Of Weight

The following trends are evident in the results:

1) The factor of weight was applied by most of the students (19 of 24).

2) The factor was applied by all groups; for example, by 5 of 6 grade eleven students.

3) The factor was applied by 9 boys and by 10 girls.

4) The factor was applied as a continuous influence in all but one of the 19 cases. This exception was a grade ten girl who interpreted it as a dissipating factor with time.

4.2312 Typical Responses - The Combined Effect Of Height and Weight

1) CLASSIFICATION - The Height and weight variables are roughly equal in effect.

Quotations - For task 3.26A:

S. - "I think that they will probably go the same speed

Table 4.5

The Combined Effect of The Independent Variables Height and Weight
(From Tasks 3.26A and 3.26B)

Group	Neither One Is Applied	Height Only Is Applied	Weight Only Is Applied	The Effects Of Height and Weight Are Of The Same Importance	The Effect Of Height Is More Important Than The Effect Of Weight	The Effect Of Weight Is More Important Than The Effect Of Height
TOTALS BY GRADE						
Grade 6	1	0	5	0	0	0
Grade 8	1	1	2	1	0	1
Grade 10	1	0	1	1	0	3
*Grade 11	1	0	3	0	0	2
TOTALS	4	1	11	2	0	6
TOTALS BY SEX						
GIRLS	1	1	4	2	0	4
BOYS	3	0	7	0	0	2
TOTALS	4	1	11	2	0	6
TOTALS BY SEX AND GRADE						
GIRLS						
Grade 6	1	0	2	0	0	0
Grade 8	0	1	1	1	0	0
Grade 10	0	0	0	1	0	2
Grade 11	0	0	1	0	0	2
BOYS						
Grade 6	0	0	3	0	0	0
Grade 8	1	0	1	0	0	1
Grade 10	1	0	1	0	0	1
Grade 11	1	0	2	0	0	0
TOTALS	4	1	11	2	0	6

*Instruction Group

down, because that heavier one will go down quite fast because it's heavy, and heavier things fall quicker, and I think they will probably fall together.: ...
I think that at first it will not be twenty-five centimetres any more ... be less. The top ball catches up a little bit. Then, they'll probably stay a certain space different ... a couple of millimetres different."

For task 3.26B:

S. - "The heavier one would catch up and probably pass the lighter one."

I. - "Why?"

S. - "The heavier one has more speed (height) and more weight, so it would probably pass the lighter one."

I. - "Why?"

S. - "The heavier one has more speed (height) and more weight so, it would probably pass the smaller one."

2) CLASSIFICATION - No cases occurred in which height was considered to overcome the factor of weight.

3) CLASSIFICATION - Weight is a much more important factor than height."

Quotations - For task 3.26A:

S. - "The distance (between) increases."

I. - "Why?"

S. - "Because that one (lower) is heavier. It has more pull. There's more weight to pull it downwards, and the speed increases."

For task 3.26B:

S. - "Between them (distance) would decrease, then increase again. Increase as it passes."

4.2313 Trends in the Data for the Combined Effect of Height and Weight.

The following trends are evident in the results:

1) 16 of the 24 students did not consider both variables at the same time.

2) 4 students ignored both variables.

3) 11 students applied weight only.

4) Only 1 student applied height while ignoring weight as a factor.

5) In no case was height considered to dominate weight.

6) 6 students considered that weight dominated height.

7) Only 2 students, both girls, applied height and weight as having equal significance.

8) Grade 6 students did not compare these two variables, although it must be pointed out that only one had applied height previously.

4.2322 Typical Responses - The Combined Effect between Initial Velocity and Weight

1) CLASSIFICATION - Initial velocity and weight have equal importance.

Subject - E.A. a grade 8 girl.

Quotation - For task 3.28:

I. - "Would the top one pass?"

S. - "Maybe just a little bit but not that much at all."

I. - "What if it fell further?"

S. - "It wouldn't change that much."

I. - "Why not?"

S. - "It'd probably stay about the same because it (top) would have a chance to get faster and faster, but this one (bottom) is heavier."

Table 4.6

Combined Effect Of The Independent Variables Initial Velocity And Weight
(From Tasks 3.27 and 3.28)

Group	Neither One Is Applied	Initial Velocity Only Is Applied	Weight Only Is Applied	Initial Velocity Is Equal In Effect To Weight	Weight Has A Greater Effect Than Initial Velocity	Initial Velocity Has A Greater Effect Than Weight
TOTALS BY GRADE						
Grade 6	1	1	3	0	1	0
Grade 8	0	2	0	1	3	0
Grade 10	0	1	1	1	3	0
*Grade 11	0	1	0	1	4	0
TOTALS	1	5	4	3	11	0
TOTALS BY SEX						
GIRLS	1	2	1	2	6	0
BOYS	0	3	3	1	5	0
TOTALS	1	5	4	3	11	0
TOTALS BY SEX AND GRADE						
GIRLS						
Grade 6	1	1	0	0	1	0
Grade 8	0	1	0	1	1	0
Grade 10	0	0	1	1	1	0
Grade 11	0	0	0	3	0	0
BOYS						
Grade 6	0	0	3	0	0	0
Grade 8	0	1	0	0	2	0
Grade 10	0	1	0	0	2	0
Grade 11	0	1	0	1	1	0
TOTALS	1	5	4	3	11	0

*Instruction Group

2) CLASSIFICATION - Weight dominates the effect on initial velocity.

Subject - G.P. a grade 11 boy.

Quotations - For task 3.27:

S. - "The space (between) begins to increase almost right away."

I. - "Why?"

S. - "Because the heavy one will go faster. The little one will increase in speed except the big one will increase faster."

For task 3.28:

S. - "I guess the light one would pass it and as soon as you dropped the heavier one, it would catch the lighter one and pass it again at some point. It will keep accelerating with that one (light) except the space (between) would keep on getting greater."

3) No cases occurred in which initial velocity had a greater effect than weight.

4.2323 Trends In the Data for the Combined Effect of Initial Velocity and Weight.

1) There was only one case from the grade 6 students in which these two variables were compared.

2) No students considered that the effect of initial velocity was greater than the effect of weight.

3) 11 of the 24 students considered that the effect of weight was more important than the effect of an initial velocity.

4.2332 Typical Responses - The Combined Effect of Height and Initial Velocity

CLASSIFICATION - The effects of initial velocity and height add.

Subject - S.S. a grade 6 girl.

Quotations - For Task 3.23A:

Table 4.7

The Combined Effects Of The Independent Variables Height And Initial Velocity
(From Tasks 3.24A, 3.24B, 3.25A and 3.25B)

Group	Neither One Is Applied	Height Only Is Applied	Initial Velocity Only Is Applied	Initial Velocity And Height Effects Add
TOTALS BY GRADE				
Grade 6	3	0	3	0
Grade 8	0	0	3	3
Grade 10	0	1	5	0
*Grade 11	0	0	6	0
TOTALS	3	1	17	3
TOTALS BY SEX				
GIRLS	1	1	8	2
BOYS	2	0	9	1
TOTALS	3	1	17	3
TOTALS BY SEX AND GRADE				
GIRLS				
Grade 6	1	0	2	0
Grade 8	0	0	1	2
Grade 10	0	1	2	0
Grade 11	0	0	3	0
BOYS				
Grade 6	2	0	1	0
Grade 8	0	0	2	1
Grade 10	0	0	3	0
Grade 11	0	0	3	0
TOTALS	3	1	17	3

*Instruction Group

S. - "I think that if it's ... they're dropped over a greater distance, the one that's got more height would gain more speed and catch up."

For task 3.34A:

S. - "Just like in the last one, I think that the one that was dropped from the highest point would still catch up 'cause it's had a head start. It's moving faster, and it's higher."

The comparisons between these two variables were much more difficult to make. Often the responses were not as explicit with respect to this comparison as in the other cases.

4.2333 Trends in the Data for the Combined Effect of Height and Initial Velocity

1) No grade six, ten or eleven students explicitly considered these variables at the same time.

2) Most students (17 out of 24) considered initial velocity only when both were present.

3) Only one student considered height alone while ignoring initial velocity.

4.24 Trends in the Data Taken as a Whole

1) Grade 6 boys did not qualify their applications of variables. In seven cases they did not apply the factors, and in five cases they applied them in a continuous manner.

2) Grade 6 girls did not apply the factors in five cases or applied them in a continuous mode in four cases. They qualified the action of the factors in three cases and applied them as short impulses in these three instances.

3) Grade 11 students had five cases of qualified actions. These factors, however, were never qualified as short impulses, but as slowly dissipating factors. They did apply the factors continuously in fourteen cases and did not apply them in five cases.

4) Almost all factors were applied by some students at all grade levels. The exception was that there were no cases in which grade 6 students had a clear expression of acceleration as varying with elapsed time.

5) Very few problems occurred in shifting frames of reference. Two grade 6 students showed slight hesitation, but they were able to adjust without a problem.

6) Among grade 6 students there was only one clear case in which two variables (initial velocity and weight) were compared.

7) The relative effects of initial velocity and weight were compared the most. There were fourteen of twenty-four such cases.

8) The relative effects of height and initial velocity were compared in three cases.

9) The relative effects of height and weight were compared in eight cases.

4.250 Explanations Given for the Response

Explanations were not easily evoked from the students. As a result, the numbers of occurrences for each explanation cannot be considered significant. Therefore, the explanations are reported and examples are given but not number of occurrences. These explanations were consistent with similar responses given by other students who offered no explanations.

4.251 Force and Height

Height is a relevant factor, because the force pulling the shotput to earth increases with height as measured from the floor.

1) EXPLANATION - The increased force is caused by thinner air.

Subject - S.G. a grade 6 girl.

For task 3.21:

I. - "Why did you make the gap bigger?"

S. - "Well, the weight, as it comes to the ground. It would start going faster 'cause the air, it's not... It's easier to drop something down 'cause the air is harder to push down up there than down here (points to the bottom), so it should drop faster."

I. - "Suppose these (shotputs) are heavy enough so the air doesn't matter. Would there by any difference?"

S. - "Not really. It should not be much difference."

2) EXPLANATION - Gravity increases with height.

Subject - T. a grade 6 boy.

For task 3.23A:

I. - "Why does the top one catch up?"

S. - "'cause the top one is heavier. 'cause it would be higher up, and gravity pulls it down more, and then the other one would have like less gravity pulling down, 'cause it's lower."

4.252 Energy and Height

Height is a relevant factor, because energy is a consideration of the size of the gap between the floor, and the shotput influences the speed of transit.

1) EXPLANATION - The top ball hits the floor harder. Therefore, it must move faster.

Subject - S.S. a grade 8 girl.

For task 3.23A:

S. - "I think that if they're dropped over a greater distance, then the one that's got more height would gain more speed and catch up ... The ball that was dropped from the higher height would hit the ground a lot harder, because it's going faster ... with more force."

2) EXPLANATION - The gap between the shotputs is a factor.

Subject - K.C. a grade 10 girl.

For Task 3.23A:

S. - "The distance (between) would continue to increase."

I. - "Why?"

S. - "Because the space (between the shotput and the floor). That one (top) has so much more (points to space between the shotputs) space to speed up."

3) EXPLANATION - The size of the gap between the shotput and the floor is a factor.

Subject - P.M. a grade 8 boy.

For task 3.23A:

S. - "I think that one, the one on the top, would go faster, because it has more room. Like this one (bottom) has less. You started it lower. This one (top) has more of a chance, because it has more space (points from the shotput to the floor)."

4.253 <u>Force And Velocity</u>

Force determines velocity which means that a constant force produces a constant speed. An increasing force is required to produce acceleration.

1) EXPLANATION - T. clearly indicates constant speed for task 3.31

Subject - T. a grade 6 boy.

He also indicates that heavier objects fall faster in task 3.36.

For task 3.31:

I. - "How do the speeds compare in each gap?"

S. - "It'd go the same."

For task 3.26A:

S. - "The heavier one would hit the floor, or would it have more space between than the other ball? Mmmm. It (the space between) widens....gets wider."

I. - "Does it continue to get wider?"

S. - "Yes."

I. - "For how long?"

S. - "Till it hits the place where it was headed."

I. - "Why does that happen?"

S. - "'cause it's the heavier ball."

I. - "What does that cause?"

S. - "The ball to drop faster."

...

I. - "What makes the ball fall down?"

S. - "Gravity."

I. - "What does that mean?"

S. - "Like it's something in the earth that sort of pulls things down and helps you stay on the ground.'cause, otherwise, if there was no gravity, you'd be floating all over the place."

2) EXPLANATION - Since acceleration occurs and velocity varies with force, then force must vary.

Subject - L. a grade 11 girl.

For task 3.21:

I. - "Why does the speed increase?"

S. - "...the pull from gravity becomes stronger, and so the ball is going to move faster."

I. - "How does it become stronger?"

S. - "Well, if you're farther away here (points to the top of the scale) If you're farther away from the pull of gravity.... farther away from the bottom.... the ground.... the pull is not as strong, because you're getting farther away from the ground."

I. - "Suppose the pull was the same?"

S. - "The speed would stay the same."

4.260 <u>The Sources of Belief</u>

Several sources of beliefs were identified. Sometimes authorities were cited. Sometimes experience was drawn on. Sometimes analogies were used, but these were few in number.

4.261 <u>Authorities Cited</u>

A great diversity of authorities were cited from cartoons to Galileo.

1) AUTHORITY CITED - cartoons.

Subject - R.H. a grade 8 boy.

For task 3.25A:

S. - "Everytime you ask me something, I just picture it in my mind. 'cause I always see it in cartoons and stuff when they drop one rock, and then they drop another rock and they always catch up to each other and then they go level."

2) AUTHORITY CITED - Galileo was cited several times. In this case he was cited with some doubts.

Subject - K.P. a grade 10 girl.

For task 3.26A:

S. - "Probably the larger one would....I don't know.... that's confusing, 'cause I remember Galileo and the big ball and the little ball. I mean he said that they fall at the same time, but that doesn't make sense."

4.262 Experiences Cited

A variety of experiences, some personal and others not, were cited to support stated beliefs.

1) AUTHORITY CITED - Personal experience with tennis balls.

Subject - K.K. a grade 8 girl.

For task 3.23A:

S. - "When I drop two tennis balls at the same time one gradually... the higher one catches up."

2) AUTHORITY CITED - Television show of the Apollo moon landing.

Subject - D.C. a grade 11 boy.

For tasks 3.26A and 3.26B:

S. - "On T.V. I'd see the Apollo land on the moon, and the feather and the hammer were dropped from about six feet, and they both landed upon the moon's surface at the same time. I was amazed at that when I saw it, because I was sure ... I thought that surely the hammer was going to drop way faster than the feather. That's probably where I picked up the idea that the big ball and the small ball would fall in the same time."

4.263 Analogies Drawn

Few analogies were drawn which were of significance. Therefore, an exhaustive list is very short.

1) ANALOGY DRAWN - A horse race is used to compare speeds.

Subject - S.S. a grade 8 girl.

For task 3.25B:

S. - "Just the ball shooting past you like a fast horse out of a gate when you are on an old nag."

2) ANALOGY DRAWN - An example is drawn using the height of the Empire State Building.

Subject - L.F. a grade 10 boy.

For task 3.24A:

S. - "It is like if you drop a penny from a stool, it's not going to make much of a dent in the ground. You drop it from the Empire State Building; it's going to go through a car and a couple of layers of pavement."

3) ANALOGY DRAWN - The falling object is compared to one rolling.

Subject - K.C. a grade 10 girl.

For task 3.21:

S. - "If you rolled a ball without friction, it would just keep going. So, wouldn't the same thing happen if you just dropped the ball?"

4.270 Revision of Response

An additional process seemed to be operating in the grade eleven physics group. In three of the six interviews the subjects gave an intuitive response, and committed themselves to this point of view. Then, later on in the interview they revised their response to give what, in fact, was a more accurate response. It is these final responses which appear on the data tables 4.1 through 4.7 . This revision of response involved some unknown aspect of the dynamics of the interview. However, one interpretation of this process is that intuitive points of view tended to persist after instruction. These may have been given first. Then, upon reflection, a point of view more consistent with learned explanations from instruction in kinematics was given. It should be noted that this revision of response occurred only in the grade eleven physics group, and, therefore, instruction in kinematics could well have been involved.

4.271 Quotations to Illustrate Revision of Responses

Subject - K.B. a grade 11 girl.

Task - 3.25A and 3.23B.

In task 3.25A there is indecision about whether an initial velocity is a continuous advantage:

S. - "The one that you dropped (top) will be going faster."

I. - "Can you predict what happens as they pass?"

S. - "It comes even. Then passes. Yours will already have an initial velocity. Yours is going to keep on going. So mine is going to be slower than yours, because it started later.

I. - "What will happen to the distance between them?"

S. - "Should stay the same. I think ... I'm not sure ... I keep on changing my mind! No. It should remain the same distance apart."

For task 3.23B there is an initial acceptance of the relevance of height, and then it is rejected:

I. - "What do you see?"

S. - "The top ball coming towards me."

I. - "And, then?"

S. - "It would be beside me and then below me."

I. - "Why?"

S. - "One's at a higher level ... been dropped from a higher level. No! No! the top ball, it's just there, staying the same distance."

Subject - B.B. a grade 11 boy.

Tasks - 3.21 and 3.23A compared to 3.23B.

For task 3.21 there is uncertainty about the continuity of acceleration:

I. - "What if it could fall further?"

S. - "It would keep accelerating. Oh no! No! No!. It would keep accelerating."

For 3.23A and 3.23B there is an initial application of the height variable and then a rejection of it:

Now, for task 3.23B:

S. - "Now that I think of it, I don't think it would (catch up) ... 'cause they're both accelerating from two different points, one lower than the other, but they wouldn't gain in speed 'cause they're both accelerating at a constant speed. I'm contradicting my last statement before. What I'm saying now is that you drop both balls at the same time, and they're at the same weight. They would stay an equal distance apart."

This student expressed concern after the interview about his change of mind. He stated that this had occurred at several points for him and that he had tried hard to be consistent.

Tasks - 3.21 and 3.24B.

Subject - L. a grade 11 girl.

In task 3.21 a theory of acceleration as caused by increasing force is advanced. In 3.24A this is rejected.

For task 3.21:

S. - "Because the ball. It's like rolling downhill. The gravity starts pulling on the ball; and it starts going faster and faster. The pull gets harder. Like you drop something and the pull from gravity becomes stronger, and, so, the ball is going to move faster."

For task 3.24B:

S. - "My thing about the gravity is wrong. I'm starting to think that is wrong. I don't know why it does hit. It's not because of the gravitational pull."

CHAPTER FIVE

CONCLUSIONS, EDUCATIONAL IMPLICATIONS AND RECOMMENDATIONS

5.00 SUMMARY OF THE STUDY

The three main objectives in this study were:

a) to identify students' beliefs concerning the motion of objects in free-fall;

b) to identify trends in the development of these beliefs among students ranging from the grade 8 to grade 11 level;

c) to identify the possible effects of standard instruction in kinematics on these beliefs for grade 11 physics students.

Individual interviews were used in the procedure with 24 students.

The interviews were analysed from two perspectives.

a) Responses were classified task by task. Totals were categorized by sex and by grade. Within each of these groupings the responses were further classified by mode of action for each variable and mode of combined action when more than one variable was involved.

b) Explanations were analysed to determine the sources of the beliefs about free-fall motion and any underlying beliefs about the related concepts of force and energy.

5.10 CONCLUSIONS OF THE STUDY

The problems addressed in this study were not presented as formal hypotheses. However, a number of tentative conclusions regarding the methods used, the beliefs about free-fall motion held by students, and the effects of instruction on student beliefs can be offered.

5.11 Method

Conclusions are presented concerning the method of collecting data, the tasks and the method of analysis.

1) The interview methodology (a modification of the Piagetian clinical interview) was effective for obtaining responses and explanations for students' beliefs.

This one-on-one method allowed the interviewer to check responses and to probe explanations. The structure provided by the protocols also generated data which could be classified in distinct categories.

2) The eight tasks used in the study can be considered valid for obtaining reliable data regarding students' beliefs about objects in free-fall.

This conclusion seems reasonable since it was apparent that the students were not confused by the tasks. They understood the instructions and were able to respond without noticeable difficulty. The novelty of the apparatus and tasks caught their interest, and they seemed at ease and willing to freely express their points of view. Ideas presented by the students were consistent throughout all of the tasks, and their explanations were not simply idiosyncratic. No signs of boredom were evident, as in most cases the students offered to stay after the interview was concluded to help dismantle the apparatus and were anxious to discuss the general problem area at that time.

3) The method of analysis in which responses were categorized task by task was an effective means to determine trends in the data.

The modes of action and interaction designated in the data tables were clearly evident in the responses. A large amount of data was obtained. This method of categorization made the volume of data manageable, and trends by grade, by sex, and by sex and grade were evident. These trends, as well as the explanations offered, have potential uses for teachers and developers of curricula.

5.12 Beliefs - Developmental Trends

A number of conclusions can also be drawn from the data regarding the development of substantive beliefs in the students.

1) Developmental trends were evident in the data collected regarding a single object in free-fall.

Although some notion of acceleration was evident at all levels, it was clear that many grade 6 students tended to view free-fall motion in terms of constant velocity, while grades 8 and 10 students had qualified notions of acceleration as not being continuous. Grade 11 physics students treated all acceleration as continuous. However, even in this grade 11 physics group the majority still believed that velocity increases as a function of displacement and not as a function of elapsed time.

2) Developmental trends were evident in the data collected regarding judgements made by the students about the relevance or effect on free-fall motion of differences in height, initial velocity and weight using two shotputs.

Although these variables were considered at all levels, some trends were evident. Weight was most important at all levels (18 of 24) including the grade 11 group where the majority considered it as relevant. Few qualifications for the mode of action of this variable were made. It simply acted continuously or not at all. Initial velocity was the second most important variable. Three of the six grade 6 students ignored this variable, while two others applied it as a short impulse only. It was applied by all of the grade 11 students, although half of these qualified its action as not being continuous. Height was the least important factor, but it was applied by over one-third of the students. It was used infrequently by the grade 6 students, by most grade 10 students and still continued to be applied by one-third of the grade 11 physics students. There were no cases in which the frame of reference variable caused any significant problems at all.

3) Developmental trends were evident in the data collected regarding the combined action of the variables.

Although a combination of variables was considered at all grade levels, there was only one case of a combined action of two variables for the grade 6 group. Of the combined actions possible, the one involving weight and initial velocity was most pronounced. Over one-half of the students considered weight to be a more important factor in determining acceleration than initial velocity when they were presented in opposing situations. There were a few cases in which they were both considered to be of equal effect. There were no cases in which initial velocity was considered to be more important than weight. In only one-quarter (5 of 24) of the cases was initial velocity considered while weight was ignored. Height and weight were considered to have a combined effect by one-third of the students. The greatest number of these were in the grade 8 and grade 10 groups, although it was considered in the grade 11 group as well. There were no cases of height being considered more important than weight. The few cases of height and initial velocity having a combined effect were all at the grade 8 level. Initial velocity dominated the effect of height.

5.13 Beliefs - The Effects of Instruction

A number of tentative conclusions can be offered regarding the possible resistance of the beliefs of students regarding free-fall motion to standard instruction in kinematics for the grade eleven physics group.

1) Although all of the physics 11 students described free-fall motion in terms of continuous acceleration, speed was believed to vary with distance fallen rather than with elapsed time. This is contrary to textbook equations in kinematics which clearly describe speed as varying directly with elapsed time not with distance.

2) Weight was considered to be a relevant factor by 5 out of 6 of the grade 11 students. The acceleration due to gravity, 'g', is considered independent of weight in kinematics. This finding, then, is a strong indication that the variable of weight should not be ignored in kinematic instruction. In fact, the one student who ignored weight did so with reservations and only because he had seen an Apollo moon experiment on television.

3) Half of the students felt that initial velocity gave a falling object a dissipating advantage, although in kinematics it is treated as giving a continuous advantage to an object which has an initial velocity over one which does not.

4) Height was considered to be an advantage by 2 of the 6 students. In Physics 11 height is usually ignored. If it were considered, in fact, height would be a very slight disadvantage, not advantage.

5) Initial velocity and weight were considered to produce a combined effect by 5 students and the combination of height and weight by 2 students. There was only one case in which initial velocity was considered as the only relevant factor. In fact, according to standard kinematics theory, initial velocity is the only factor.

5.14 Explanations and Sources of Beliefs

A number of tentative conclusions can be offered regarding the explanations given by the students.

1) Certain sources of the beliefs and explanations came to be evident.

In some cases experience was drawn on, but in others various authorities were simply cited and accepted. Few true analogies were actually drawn.

2) Certain related concepts were considered to be factors affecting free-fall motion.

Concepts of force as they affect motion were a factor. Either velocity or acceleration could be considered to vary with force. For example, the students' conception of the nature of the force of gravity (as constant or as varying) would affect their concept of free-fall motion.

3) A number of cases of revision of responses are evident.

Three cases involving a revision of a student's original response took place for the grade 11 group. The interview data indicates that either there was a conflict between common-sense beliefs and ideas presented in the kinematics instruction or there was a greater ability to learn from the tasks themselves than for the other groups.

5.20 EDUCATIONAL IMPLICATIONS

A number of implications for instruction and curriculum design arise from this study.

1) The common-sense world of the student does not correspond exactly to the idealized world of kinematics.

In the common-sense world the mass of objects is a factor because of air friction and the occurrence of terminal velocities. Force is required to keep objects and mechanisms, like an automobile, in motion at a constant velocity. Motion ceases unless force is applied to overcome friction in various internal parts. Beliefs about motion arise from experiences in this common-sense world, and these beliefs need to be addressed by instruction. The student should be allowed to test the relevance of such factors as weight and height in addition to that of initial velocity. This may suggest more generally that in an instrutional setting variables are too quickly narrowed to those relevant in the idealized world without letting the student test others that he believes to be relevant to the phenomenon (Cole and Raven, 1969).

2) The notion of readiness is not as clearly useful with respect to concepts of motion, as might be assumed.

All of the grade 6 students were quite able and willing to consider the problems in the tasks. It seems evident that motion need not only be considered as a set of complex problems for which involved algebra is needed. Many of the ideas touched upon in the tasks could easily be translated into activities which would be appropriate for all levels used in the study. The grade 6 students did not generally consider the combined effect of more than one variable and tended to have a less developed view of free-fall motion. However, it would appear that students at even the grade 6 level are able to deal with the concept at least on a qualitive level.

3) Instruction in kinematics should be more than an explication of known ideal results.

Students ought to be able to explore their own beliefs and explanations. Understanding does not seem to develop only from analysing the data obtained from rather contrived experiments in standard instruction which do not necessarily relate to their own experience of characteristics of motion. Some suggestions are noted in Chapter Two (Section 2.40) to provide for this. Exploring these ideas in small groups was suggested. Testing the ideas using 'anomaly maneuvers' and reconciling contradictions using 'reconstruction maneuvers' was also suggested (Erickson, 1979). This would allow the student to accommodate new information.

4) The way in which variables were considered by the students has implications for instruction.

Variables were not thought simply to be relevant or not relevant. They were also judged to act in short impulses or with a dissipating effect. This aspect, then, namely, the mode of action of a variable, needs to be addressed in instruction as well as the issue of the relevance of the variables. Activities, then, need to consider this aspect of the instructional problem with respect to motion.

Thus, the study indicated that the common-sense world of the student contains a rich source of beliefs which need to be addressed in instruction. Students need to be able to explore the relevance and action of variables they believe to be related to problems of motion. This implies that they will be involved in the designing of experiments to test their ideas. Alternative activities should also be available, since not all students have the same beliefs.

In addition, it is evident that the teacher needs to be sensitive to the beliefs of the student. The teacher needs to create an atmosphere in which the student feels free to express and test his beliefs without being intimidated by a feeling that only 'right' answers will be considered.

5.30 RECOMMENDATIONS FOR FURTHER RESEARCH

A number of follow-up studies would greatly clarify and strengthen the overall implications of this study.

These recommended studies are:

1) Develop a group instrument which uses many of the tasks of this study. This would allow for a replication of the results of this study using a much larger, carefully-controlled sample of students.

2) Design a set of tasks which specifically examines the relationship between force and motion; in particular, the case where gravity supplies the force.

A developmental study of dynamics would clarify further this aspect of motion. The student, it seems, may consider force and motion together and not motion in isolation without considering its cause.

3) Conduct a controlled experiment testing the effects of standard kinematics instruction. This also could compare the effects of other forms of instruction which specifically addressed the beliefs of the students as well as their effect on the students' ability to solve quantitative problems of motion.

4) Determine if the constructs of 'variable relevance' and 'mode of action for variables' apply to the study of different concepts in physics. These have been useful distinctions in this study and may have a more general application.

5) Carry out similar clinical investigations for other science concepts, such as light transmission or inertia.

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APPENDIX

TRANSCRIPT OF AN INTERVIEW

The following interview was chosen because it illustrates some of the dynamics of the interview process. K.B., the subject, was a grade 11 girl who had received instruction in kinematics. This interview also illustrates the 'changing of mind' referred to in section 4.270 which occurred only with the grade 11 group.

K.B.'s Interview

A few minutes were spent in making K feel at ease before the tasks were actually started. She was told that the interviewer was interested in what she really thought about the problems. She should not be concerned at all about whether her answers were right or wrong or whether they were what she thought the interview wanted her to say. She was also told that this interview was not a part of the Physics 11 course. The interviewer was attempting to identify students' beliefs about falling objects so that these ideas might be taught more effectively.

I: Interviewer ; S: Subject

I: "I've got a timing device. Get a stool. Get up on it, and I'll show you how it works."

S: "Ahem"... (Gets the stool and looks at the digital timer).

I: "This is an electronic timer. It reads in tenths of a second and seconds. Okay?"

S: (With pointing to the scale) "This is seconds?"

I: "No. This is tenths of a second."

S: "Aha."

I: "We'll be sticking mainly to this column."

S: "Oh. Okay."

I: (With pointing) "Now this is a photocell which means that the light goes into that (points) and closes a switch. When I block out the light it starts the timer."

S: "Ahem. Okay."

I: "When I block out the second light it stops the timer."

S: "Okay."

I: "So that if I put my hand through there, for example ... Would you watch the timer."

S: "All right."

I: (Performs action) "Go through the first one (starts timer) ... and the second one and it stops."

S: " That means that we've got ... It took about four-tenths of a second."

I: "All right, would you do that, too, please.:

S: (Performs action).

I: "Keep your hand together. Don't let your fingers separate."

S: "Could I just stop in the middle?"

I: "Yes. Go through just fairly fast now."

S: "What if you only block the light off partway?"

I: "Well it ... There's a certain point where the switch turns on and off."

S: "Oh, I see that. Okay." (Performs action).

I: "Now, how long did that take?"

S: "Ahem ... three point three seconds."

I: "All right. Go through it a bit faster."

S: (Performs action).

I: "That took..."

S: "Point eight seconds."

I: "Again, faster."

S: "(Performs action).

I: "That took..."

S: "Point two seconds."

I: "All right. What happens to the time if you go through faster?"

S: "The time is less."

I: "If you go slower "

S: "The time increases."

I: "Now, suppose that I increase this distance (separation between photocells). Suppose I put the second timer down to here (20 cm gap) and I move through at the same speed that made two-tenths of a second before. What would the timer read then?"

S: "If you moved at the same speed?"

I: "Yes."

S: "Oh, it would depend on how far you moved it down."

I: "Suppose we moved it twice as far?"

S: "Oh, it would be four-tenths of a second."

I: "All right. Suppose that I moved it down to here and made the space bigger. What would I have to do to make the timer read two-tenths of a second the same as before?"

S: "You'd have to speed up."

I: "All right. So, do you think you understand the timer?"

S: "Yes."

I: "Now we're going to time an object. Could you give me that indoor shotput there?"

S: "This one?"

I: "Yes, the red one; either one of the red ones."

S: "Okay."

I: "It's pretty heavy."

S" "Yes it is. Really!"

I: "Now, what I m going to do is time this first gap."

S: "Ahem."

I: (Performs action of dropping the shotput through the timer). "How long did it take?"

S: "One-tenth of a second."

I: "Now you see, that's about 10 cm."

S: "Yes."

I: "Now, suppose that I dropped the ball from here (0 cm mark). It falls all the way down."

S: "Right."

I: "Now suppose I put the first of these photocells, say, at fifty."

S: "All right."

I: "Now, it s the same ball that's dropping.

S: "Yes."

I: "It'll fall down past the first photocell. Where would you have to put the second photocell so that it would read one-tenth of a second again?" (Simulates action).

S: "This was 10 cm, so you'd have to put it farther apart." (Puts it at the 90 cm mark).

I: "Yes, put it at 90 so that you made the gap about 40 cm. Could you just tell me why you did that?"

S: "Well, because it accelerates as you drop it. In one-tenth of a second it's going to drop 10 cm up there (points to the top). It's going to go quicker. It's going to accelerate, which means that in a shorter time it's going to go more distance as it drops farther and farther."

I: "Now suppose that we put the first timer at 100. About where would you put the second photocell so that it would take one-tenth of a second between these two?"

S: "Ahem...here."

I: "About 170?"

S: "Yes."

I: "Suppose we put the first timer at 150; where would you put the second timer?"

S: "Quite close to the bottom here. Maybe a bit off."

I: "More than 250?"

S: "Aaa... No I guess that would be about right. About that."

I: "About 250?"

S: "Yes."

I: "Now, suppose you put the first timer at 200; where would you put the second?"

S: "About 300 or so."

I: "Could you just tell me again why you're making ... what is happening to the speed of the body as it's dropping?"

S: "The speed of the body is accelerating, which means that in the same amount of time it's going to fall further."

I: "Suppose that it could fall for a long distance?"

S: "Ahem."

I: "You know, fall right through a hole in the floor and keep on going. Can you say anything about the speed in that case?"

S: "It would accelerate."

I: "Would it accelerate indefinitely?"

S: "Are you saying that it's falling indefinitely?"

I: "Well suppose it could fall for a long distance."

S: "Well, it's going to be accelerating until it hits the ground, because you've got no upward force. Well none to really speak of."

I: "Suppose that it fell, say, 100 metres or even a longer distance. Would it make any difference?"

S: "To the acceleration?"

I: "Yes."

S: "Are you saying, would it still accelerate?"

I: "Yes."

S: "Yes it would."

I: "Let's go back and look at this gap here. Now, you had one at 100 and the other one at 170. In this centre gap where is it going the fastest?"

S: "Right down here (170 mark)."

I: "At the bottom?"

S: "Yes."

I: "And where is it going the slowest?"

S: "Right at the top (100 cm mark) where the gap starts."

I: "Where is it going exactly half the speed between the two?"

S: "Ahem... Considering what we know, if we knew the two velocities, we'd add them up and divide by two."

I: "Yes. So, about where would it be going that half-way speed?"

S: "I think it's about here or so."

I: "So, in a gap of 60 you're pointing about 20 down from the top. Why would it be going the half-way speed there?"

S: "It's always accelerating...so if we...mmm...it just seems logical to me. I don't know why, but it does. I don't think it would be going half-way between the two in the middle. I don't think lower. I think it's about 20 down."

I: "Now a couple of other problems. We have two shotputs here. They're just the same."

S: "Yes."

I: "Could you get up on the stool here?"

S: "Okay."

I: "In this case we're going to use two together. You hold that one down at 25."

S: "Okay." (Does so).

I: "And I'm going to hold this one up at 0." (Does so).

S: "Ahem."

I: "Now, suppose that we count one, two, three, go, and we both let the shotputs go at exactly the same time."

S: "At exactly the same time?"

I: "Yes. Can you tell me what will happen... Can you describe the distance between the two as they fell?"

S: "The distance between them should stay the same, because ...we have the force of gravity is the same, in both cases. They both weigh the same. The one that is higher just gets to accelerate longer. So, I think they will stay the same."

I: "Now, suppose that we put the second one down at 100. You can get down off the stool."

S: "Okay."

I: "Now, hold that one down at 100 (Does so). I put this one up at 0 (Does so) and I drop it (Simulates action). You wait until it's at 40. Just when it's at 40 you drop yours. Now, what will happen to the distance between the two as they keep falling?"

S: "The distance between the two will decrease because this one (top) has already accelerated to this point (40 cm). So, it's going to be going faster. And, this one (bottom) which is just starting to accelerate... This one (top) will always have more... Its velocity will always be greater because it started first."

I: "Will it catch up?"

S: "Yes. I think so."

I: "Will it pass?"

S: "Yes."

I: "What about the space between the two after that?"

S: "I think it would continue to increase."

I: "Now, another situation. Suppose I put that one at the top (does so) and you held yours at the 100 cm mark (Does so). I dropped it, and you waited until it was just even (Simulates action)."

S: "Okay."

I: "In that case just when it was even, you dropped yours. What would happen then?"

S: "Well, this one is going to be going a lot faster; the one that you dropped."

I: "Okay."

S: "And, you're going much faster. And, this one... It's gonna start out and... Oh! I think they will just stay the same distance between them."

I: "Can you just run by that one again. It comes even, and then it passes. Then what happens?"

S: "Okay, just wait... This (top) one's gonna come even. It's gonna pass. The one that you dropped. And mine's gonna start out. Yours will already have an initial velocity. Yours is going to be always started, so... yours is going to keep on going, so mine is going to be slower than yours, because it started later."

I: "So, what is going to happen to the distance between them after it passes?"

S: "I think it should stay the same."

I: "How far will it go past?"

S: "Ahem... I think... I'm not sure. You mean in exact distance?"

I: "No, just approximately."

S: "I'm not sure, but it should remain the same distance apart. I said the opposite before in the last problem. I think I was wrong. The top one has an initial velocity, but...they're only advancing. They're the same bodies, so the distance (after passing) should stay the same between them, I think. I don't know what it will be, but it should stay the same."

I: "I'm just going to ask you these three in a slightly different way."

S: "Okay."

I: "In the first case imagine that you're sitting on the bottom shotput. And, you're riding on it, but your presence there doesn't change anything."

S: "Okay."

I: "So, we have one 25 cm on top of the other (Simulates action)."

S: "Yes."

I: "And we let go both at the same time. As you ride the bottom shotput down, you look up. What do you see?"

S: "The top ball coming towards me."

I: "And, then?"

S: "It would be beside me and then below me."

I: "Why would that happen?"

S: "One's at a higher level...been dropped from a higher level. No! No! The top ball. It's just there staying the same distance. It should always be above me if they're dropped at the same time. It's falling at the same speed I am."

I: "Now, suppose we repeat the second example. You ride the bottom one. It waits at the 100 cm mark. I drop the first one from the 0 mark. (Simulates action). You wait until it is at the 40 cm mark. Then, the one you are on is dropped. Remember, you are just an observer. Your presence doesn't change anything. You ride the bottom one down and look up. What do you see?"

S: "The top ball coming towards me... Then, I see it beside me and, then, below me. Then, I'd see the bottom ball... I think that it's just going to be below me. It's not going to be falling quicker or anything. It doesn't seem logical to me that it should be going faster."

I: "Now, the third problem. I drop the first one from 0. You wait at 100 till the top one is even (Simulates action); then, yours is dropped. You ride it down. What do you see?"

S: "I look up. Then, I see the one that was dropped earlier falling ...passes me, and, then, it's going to be going the same speed as I am."

I: "A couple of other combinations, okay?"

S: "All right; sure."

I: "Now, you hold that one (heavier shotput). You see, it's quite a bit heavier than this one."

S: "Yes, it is." (Verifies)

I: "Now, suppose you put that one at 25 (Does) and I put the lighter one at 0 (Does). We count one, two, three, go, and drop both at the same time. Can you describe the space between the two as they fall?"

S: "It's going to grow...because this one (bottom) is heavier; so it's going to fall quicker. The heavier you are, the quicker you fall."

I: "Suppose that I did the same thing again, but I have the heavier one at the top (Does), and you have the lighter one at the bottom (Does)."

S: "The top one is going to pass the bottom one. The distance between them is going to increase."

I: "Now, do you remember the second problem with two shotputs?"

S: "I think so."

I: "This time you hold the heavier one at the 100 cm mark."

S: "Okay (Does so)."

I: "I hold the lighter one at 0 (Simulates). I drop it, and you wait until it is at 40 (Simulates). Then, you drop yours. What is going to happen now?"

S: "The distance between the two...this one (top) is going to have an initial velocity...ahem...the distance between the two is 60 cm...the distance between the two will increase."

I: "Right from the start?"

S: "Yes."

I: "Now, the third problem with shotputs. Now, you hold your heavier one at 100 (Does). I hold my lighter one at 0 (Does). I drop mine, and you wait (Simulates). You wait until mine is even with yours, and then you drop yours, too. What happens?"

S: "The lighter one is going to be going...it's going to be farther down than the heavier one, and then the heavy one is going to speed up and pass the light one."

I: "Thank you, K. Do you have anything to add to any of your explanations?"

S: "The heavier that an object is, the more pull there is acting on it to fall... Well, the force is always the same, but, the heavier an object is, the more quickly it falls because of gravity."

I: "Thank you, K., for being so open about your thoughts. I hope you have enjoyed doing the problems."

S: "Yes, I did."

I: "Just one request...Please do not speak to anyone about the problems. I have other interviews to do, and I really would like not to have talked about them ahead of time."

S: "Sure, I see that. Thank you."