DOCUMENT RESUME

ED 294 739 SE 049 133

AUTHOR Pirkle, Sheila Farrell; Pallrand, George J.
TITLE Knowledge Representation about Projectile Motion in Junior High School Students.
PUB DATE Apr 88
NOTE 69p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (61st, Lake of the Ozarks, MO, April 10-13, 1988).
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC03 Plus Postage.
DESCRIPTORS Cognitive Processes; Computer Uses in Education; *Gravity (Physics); Junior High Schools; *Junior High School Students; *Learning Processes; Mechanics (Physics); Motion; *Physics; *Problem Solving; Science Education; Secondary Education; *Secondary School Science
IDENTIFIERS Field Theory; Group Embedded Figures Test (Witkin); Science Education Research

ABSTRACT

Research indicates that novice problem solvers represent and organize knowledge differently from experts. The novice engaged in problem solving activities is of interest to educators because efficient instruction reduces the differences between initial intuitive knowledge representations and the true concepts to be mastered. A particular cognitive style, namely, field dependence/field independence, affects the way in which information is perceived and processed. In this study, 39 junior high school aged students, identified as field dependent or field independent, were individually questioned about their understanding of the effect of gravity on vertical, horizontal, and projectile motion. They were given the opportunity to compare or verify their responses with information presented graphically on a computer monitor. Probe questions were organized to access increasingly more abstract levels of knowledge. Student responses were qualitatively analyzed and grouped according to progress through the Pattern Matching Phase, Transformation Phase, and Post-Experimental Phase. The groups were then examined for mean score on the Group Embedded Figures Test (GEFT). It was found that success on the Transformation Phase was positively associated with high performance on the GEFT. (Author)

KNOWLEDGE REPRESENTATION ABOUT PROJECTILE MOTION

IN JUNIOR HIGH SCHOOL STUDENTS

by

SHEILA FARRELL PIRKLE, Ed.D.

GEORGE J. PALLRAND, Ed.D.

The Graduate School of Education
Rutgers, The State University of New Jersey

April 1988

ABSTRACT

Knowledge Representation About Projectile Motion in Junior High School Students

Sheila Farrell Pirkle, Ed.D

George J. Pallrand, Ed.D.

Research indicates that novice problem solvers represent and organize knowledge differently from experts. The novice engaged in problem solving activities is of interest to educators because efficient instruction reduces the differences between initial intuitive knowledge representations and the true concepts to be mastered. A particular cognitive style, namely, field dependence/field independence, affects the way in which information is perceived and processed.

In this study, thirty-nine junior high school aged students, identified as field dependent or field independent, were individually questioned about their

understanding of the effect of gravity on vertical, horizontal, and projectile motion. They were given the opportunity to compare or verify their responses with information presented graphically on a computer monitor. Probe questions were organized to access increasingly more abstract levels of knowledge in the subjects. Their responses were qualitatively analyzed and grouped according to progress through the Pattern Matching Phase, Transformation Phase, and Post-Experimental Phase. The groups were then examined for mean score on the Group Embedded Figures Test (GEFT). It was found that success on the Transformation phase was positively associated with high performance on the GEFT.

TABLE OF CONTENTS

KNOWLEDGE REPRESENTATIONS ABOUT PROJECTILE MOTION IN JUNIOR HIGH SCHOOL STUDENTS

Sheila Farrell Pirkle, Ed.D.
George J. Pallrand, Ed.D.

The Problem

Science may be regarded as a vast collection of knowledge; it is growing exponentially in volume so that fifty percent of what is currently known was discovered in the past fifteen years (Ziman, 1984). It may also be thought of as a problem solving discipline whose very methodology yields that prodigious quantity of information.

Modern technological society is utterly dependent upon science for producing the devices it has come to need. Yet science is regarded by most as a subculture whose contents are uninteresting, irrelevant to day-to-day problems, and too difficult to be learned. Evidence indicates that these perceptions dominate student attitudes by the time students reach seventh grade (Yager & Yager, 1985).

Schools are charged with the responsibility for science education. Science educators appear to be confronted with an impossible assignment: the determination of what students should be required to master from the vast body of knowledge. Previous reforms in science programs focused on broad concepts and the discovery method, with no significant improvement in the educational outcome. Information processing theory, with the related development of cognitive science, has restructured the problem of "what to teach." As the understanding of how the mind solves problems grows, it becomes more obvious that goals tied to mastery of factual information should be de-emphasized in favor of problem solving skill development.

What is required, if problem solving instruction is to be an achievable goal of science education, is a description of the problem solving activities of the adolescent. The characterization of the representations of adolescents will provide insight into how problem solving ability develops and will add to the growing body of information about problem solving in general. With this knowledge, it will be possible to improve curricula in problem solving instruction in the middle school years by planning strategies that will reduce the magnitude of the difference between students' intuitive knowledge structures and true concepts.

Background

Understanding what is meant by problem solving skills is an area of research whose basis resides in Gestalt psychology, Piaget's theories of cognitive development, and information processing theory.

According to the information processing theory (Newell & Simon, 1972; Tuma & Reif, 1982), heuristic reasoning is used to transform a specified initial problem into a specified goal state, ideally using the least effort and with optimum effect (Haugeland, 1985).

The research on problem solving has been advanced by the "thinking aloud" procedure (Ericsson & Simon, 1984) where subjects describe what they are thinking as they work through an exercise. It has also been advanced by the interpretation of the subjects' drawings, produced while thinking aloud, as external representations of their mental models (Larkin & Simon, 1987).

Mental models are internal representations of perceived or imagined events (Johnson-Laird, 1983). The pre-problem-solving mental model of a student suggests the solution to the problem. The closer the match between the initial mental model and the desired mental model, the fewer are the steps needed to solve the problem and the more likely is the desired outcome. Stevens and Collins (cited in Leeds, 1986) defined learning as a process of altering mental models to make them align more closely with reality.

Without the existence of some workable mental model, it is doubtful that students can operate on knowledge, transform and reformulate it to gain the fresh insight needed to solve a problem (Pallrand, 1987a). Studies on mental models in the realm of science have been carried out by several researchers. Norman (1983) researched mental models of calculators; DeKleer and Brown (1983) studied mental models of doorbells; DiSessa (1983) and McCloskey (1983) both examined mental models of the laws of motion; Gentner and Gentner (1983) described mental models of machines; Leeds (1986) characterized the mental models of a biological system.

One of the research models that has been employed is the comparison of the expert with the novice and with the naive problem solver in puzzle format and game format as well as in standard introductory physics text problems (McDermott, 1982). Another research paradigm involves the use of nonstandard types of problems to see how the subject performs when the traditional algorithms appear not to be immediately relevant (DiSessa, 1982;

McDermott, 1982; Pallrand, 1987a; Williams, Hollan, & Stevens, 1983; Young, 1983).

Both research models yield valuable information about the mental processes employed during problem solving, especially in the case of the naive or novice. What these subjects bring to the task are life experience and intuition. Their background knowledge, however, consists of fragments of information about the components of physical events. Experience suggests that the laws of intuitive physics may not mirror the laws of nature (Anderson, 1981). It has further been suggested that these incorrect mental models may even interfere with the learning process (Larkin, 1983; McCloskey, 1983). When a problem is perceived, students retrieve the intuitive mental model from memory. They then determine if the event fits the model. Minsky (1969) refers to this decision making step as a perceptron. The "fit" determination may be a pattern matching phenomenon, or it may be the abstraction of the salient parts and reformulation of the pieces into a new mental model.

These studies have all been focusing on the problem solving behaviors of teachers, graduate students, secondary students, and other mature individuals. Despite what has been learned from these studies, the understanding of problem solving and its meaning for science education are far from complete (Good & Smith, 1987).

The focus on expert versus novice and then on nonstandard problem types has elicited characterizations of problem solving strategies as either successful or not successful. While it is useful to know about these descriptions, it would be far more valuable for the science teacher to understand how classroom students are representing the problem and what strategies they have available to them. Determination of the students' intuitive mental model of the problem and its correlation with the laws of nature would also be valuable (Anderson, 1981).

Piaget's characterization of the stages of intellectual development has been applied in the classroom by suggesting certain experiences students should have before movement to higher cognitive levels is possible (Furth, 1969). According to Piaget, the ability to operate on abstract problems develops in adolescence; it is revealed as new knowledge derived from experience with particular events. As stated previously, however, experience may interfere with problem solving success, as indicated in the studies of many researchers including Levine (cited in Eysenck, 1984, p. 275), Maier (cited in Eysenck, p. 273), Mayer and Fay (1987), Pallrand (1987a), Weisberg and Alba (cited in Eysenck, p. 27?).

Gestalt psychology emphasizes the importance of "perceptual set" in problem solving. According to the Gestalt theory, proper apprehension of the problem parts ensures that the solution will be produced (Duncker, 1945). This theory implies that new knowledge is not as essential as fresh insight is to solving problems.

Recent research has indicated a link between standing on a test of field-dependence-independence (a test of ability to visually perceive embedded information) with performance on Piagetian-type tasks (Pascuale-Leone, 1979; Strawitz, 1984) and with performance on tests of spatial ability (Jackson, 1986; MacLeod, 1986; Palmer, 1986), which is related to ability in science problem solving (Witkin, Moore, Oltman, Goodenough, Friedman, & Owen, 1977).

An adolescent population selected for its field independence would be the most likely to be successful at both pattern recognition and the disembedding of the salient features of a complex physical problem. Members of that group would also be mature enough to have formed, through accumulated experiences, primitive mental models of ...sical phenomena that govern their lives. Gravitational ..., projectile motion, and frictionless horizontal motion are such phenomena. With this population interacting with problems employing these phenomena, gains can be made in the characterization of problem solving activities and the mental models of adolescents.

Procedures

The purpose of this study is twofold: (a) to characterize the qualitative mental models of relatively field-independent and field-dependent adolescent learners about projectile motion, and (b) to compare the performance of field-independent and field-dependent students on the *Flight Protocol*. A *mental model* is defined for the purose of this research as the subject's knowledge representation. An *intuitive mental model* is defined as that knowledge representation held prior to the experiment.

Method

Students from heterogeneously grouped ninth grade science classes were administered two measures: (a) the Group Embedded Figures Test (GEFT), and (b) the *Flight Protocol* (Pallrand, 1987b).

The Group Embedded Figures Test provided a measure of cognitive style known as *field independence* or <u>field dependence</u>. Cognitive style is the "individual's characteristic ways of processing information" (Witkin et al., 1977, p. 2).

> Relatively field independent persons are more likely to experience parts of a stimulus field as distinct from the field as a whole ... they perceive analytically. Relatively field dependent persons, on the other hand, tend to experience the field according to the dominant properties of its overall organization, so that its parts are not readily apprehended as separate from the whole. (Witkin et al., 1977, p. 3)

The GEFT was given to classes of students, and the standing of the students was revealed only after they had completed the <u>Flight Protocol</u>. At that time, a balanced set ot 20 males and females who were relatively field independent and a balanced set of 20 males and females who were field dependent were sought. In all, 10 male field independent, 10 female independent, 7 male field dependent, and 12 female field dependent subjects completed the <u>Flight Protocol</u> and were included in the study.

The <u>Flight Protocol</u> (Pallrand, 1987b), a nonstandard physics problem programmed for presentation on a computer monitor, and a set of structured questions (see Appendix A for questions & Figures 1 through 10) were administered individually in a clinical interview format. The interview lasted about one hour. Subjects were encouraged to talk aloud and draw diagrams while responding to the questions. The questions involve the subjects in making predictions about what will happen, given a set of variables related to projectile motion in a gravitational field. Once the prediction has been made, the computer representation is generated, and the subjects can compare their own interpretations with those on the monitor. Thus, the computer, the drawings, and the audible responses all provide feedback in the subject's problem solving activities. During the interview, the subject may also manipulate and refer to a cardboard box and a stick figure to represent the three perspectives invoked in the latter part of the Protocol.

The Flight Protocol (see Appendix A) consists of a structured problem sequence divided into four phases. The first phase establishes the intuitive or background knowledge of the subject about vertical, horizontal, and projectile motion in a gravitational field. The second phase, "Pattern Matching," asks the subject to predict the path, as seen from the side, of an object shot from a cliff at a velocity of 4, a velocity of 8, and a velocity of 100. At two points in this part of the Protocol, the student is asked to compare the lengths of the paths and the landing time for the projectiles. The third phase, "Transformation," requires the subject to predict the shape of the projectile's path and indicate the speed of its fall, as seen from two additional perspectives: (a) from behind the cliff (View B), and (b) from below the cliff, looking straight up (View C). The subject is asked to describe these views for the projectile at velocities of 4, 8, and 100. The subject is asked to compare the landing time for the projectile as reported from each perspective.

The final part of the Protocol, "Post Experimental," asks the subject to state what he/she understands about the effects of gravity on a falling object and then on a thrown object.

Measures

The subjects were identified by number. The tape-recorded verbal responses were keyed to the respective diagrams. A code was developed and used to record the responses as successful cr unsuccessful. Answers to questions, and statements elaborating on the subject's theories and mental models were transcribed.

The overall sequential progress of the subjects as they moved from the Intuitive Knowledge to Pattern Matching, Transformation, and Post- Experimental Knowledge, was characterized.

Subjects who failed to correct erroneous solutions after looking at the computer representations of the timing of vertical motion, and timing and shape of the path of the projectile in the Intuitive Knowledge phase, and then failed to correct the diagram of the path of the object shot at velocity 4, formed Group 1.

Subjects who made progress intermittently throughout the Protocol, but were largely unsuccessful with the Transformation phase, formed Group 2.

Subjects who made progress throughout the Protocol and who were also particularly successful with the Transformation phase, formed Group 3.

A comprehensive description of representative examples of members from each of these three groups serves as the qualitative analysis of the adolescent problem solutions in this study. An analysis of the standing of students of these three groups on the GEFT was performed. An additional analysis of the relationship between the relative standing on the GEFT with adjusted total test score on the Protocol (see Appendix B, Figure 11) was also performed.

Qualitative Characterization

The qualitative characterization of knowledge representations of the subjects as they progressed through the sequences of problem solving activities in the Flight Protocol (Pallrand, 1987b), is divided into four parts:

1. Intuitive knowledge representations of the subjects in general about vertical, horizontal, and projectile motion
2. Solution responses exhibited by Group 1
3. Solution responses exhibited by Group 2
4. Solution responses exhibited by Group 3

Part 1: Intuitive Knowledge Representations

Vertical motion. All subjects represented vertical motion with an approximately straight line perpendicular to the base of the page on which they drew. Twenty-eight subjects indicated that the tick marks should be evenly spaced on the vertical path (see Appendix B, Figure 12); the remainder of the subjects represented the tick intervals as gradually increasing from top to bottom (see Appendix B, Figure 13). The latter indicated a theory of vertical acceleration. Upon seeing the computer representation of the vertical path, most of the subjects verified or corrected their diagrams. As Figure 14 (see Appendix B) indicates, when a change was made, twenty subjects organized the tick intervals with increasing distance from top to bottom; three drew the intervals increasing from bottom to top; the remainder redrew the diagram but continued to show even spacing.

Horizontal motion. All subjects represented horizontal motion as an approximately straight line path perpendicular to the vertical. On the path, marks were drawn approximately evenly spaced to indicate the ticks (see Appendix B, Figure 15).

Projectile motion. The intuitive representation of the path of a projectile in the response of 25 subjects was shown as a flat horizontal line curving into either (a) a diagonal line (see Appendix B, Figure 16), (b) a vertical line (see Appendix B, Figure 17), or (c) an inward curving line (see Appendix B, Figure 18). Four responses showed an initial upward arc. Ten subjects diagrammed the projectile path as a parabolic curve from the top of the vertical axis. The placement of tick marks varied. Some subjects showed a decrease in interval size at the curve from the flat horizontal to the more vertical part (see Appendix B, Figure 19); some placed tick marks in an even pattern (see Appendix B, Figure 17); and one showed the tick marks as decreasing in distance from top to bottom (see Appendix B, Figure 16). Eight of the subjects did not correct the projectile path shape or tick placement after viewing the computer representation. Seven subjects diagrammed the shape and placed tick marks to indicate a continuously downward slope with increasing interval marks in this Intuitive Knowledge representation phase.

When the data are examined, three separate patterns of solution responses emerge:

1. Subjects fail to (a) analyze the information given in the computer-generated diagrams, (b) extract the salient points, and (c) verify or correct their knowledge representations.

2. Subjects correct erroneous representations most of the time by matching patterns presented on the monitor, but they neither analyze the information given nor extract the salient points to consistently apply what is presented and to assert concept generalizations.

3. Subjects (a) analyze the information given in the computer-generated diagrams, (b) extract the salient points, and (c) verify or correct their knowledge representations. Some of these subjects are able to assert concept generalizations about projectile motion.

Table 1 illustrates the mean GEFT score for Groups 1, 2, and 3.

Table 1

Mean GEFT Score of Groups 1, 2, and 3

Group	N	Mean score on GEFT
1	8	10
2	26	11
3	5	17

When the groups were inspected for performances on the GEFT, it was found that the mean GEFT score for Groups 1 and 2 was almost the same, but the mean GEFT score for Group 3 was substantially higher (see Table 1).

The patterns of solution responses described in items 1, 2, and 3 above divided the subjects into three groups for the description of the knowledge representations that follows.

Group 1: Pattern of Solution Responses

Group 1 had a persistent difficulty with integrating the horizontal and vertical components of projectile motion. They were the least successful subjects at utilizing the-abstract information presented on the computer monitor. Eight of those included in the study were in this group.

The diagrams made by Group 1 subjects often depicted concrete objects such as balls and stick figures, and labels such as the words tick and cliff.

Pattern Matching. After having been directed to diagram the path of the object shot from the cliff at velocity 4, Group 1 subjects showed the path as a flat horizontal which curved fairly sharply into either a vertical or diagonal curve. The speed of the projectile was represented variously:

1. Spacing of tick marks was regular, as represented in Figure 20 (see Appendix B).
2. Wide spacing of ticks gradually decreased to narrower spacing, as represented in Figure 21 (see Appendix B).
3. Wide spacing of ticks were placed on the horizontal, narrower spacing at the curve, and wide spacing on the vertical, as represented in Figure 22 (see Appendix B).
4. There was lack of obvious pattern in the spacing, as represented in Figure 23 (see Appendix B).

When given the computer-generated representation of this path, Group 1 subjects did not redraw their diagrams.

At the next step, the subject-generated representation of the object shot at velocity 8, most of these subjects persisted in representing the path in a similar manner to their path of the object shot at velocity 4, but extended farther along the horizontal. A few changed their diagrams upon viewing the computer-generated representation of the object at velocity 8.

When responding to the question about the relative lengths of the paths of the objects shot at velocity 4 and 8, Group 1 subjects correctly identified the velocity 8 path as being the longer one. However, none of these subjects recognized that the objects both had the same flight duration. None of these subjects in Group 1 successfully completed the part of the Pattern Matching phase of the Protocol in which they were asked to draw the path of an object shot at a velocity of 100. The purpose of the question was to determine if the subjects could extrapolate the pattern in the sequence of parameters--velocities 4 and 8--to an extreme condition. This group, in general, made a diagram that curved the same way as did the curves of the paths of the object at velocities 4 and 8, and they made no attempt to discuss the limits of the paper size. Usually many more ticks were drawn, as if to indicate that more time transpired during the flight of the object at velocity 100 than at the other velocities. The oral commentary during this part of the Protocol indicated that, in general, subjects believe that objects shot at high velocities behave differently from objects shot at low velocities. When shown the computer representation (see Appendix A, Figure 6), comments indicated that the subjects felt that the computer "thought" the object would either never land, or the path would curve suddenly and the object would drop vertically "when gravity took over."

The questions that were asked for the purpose of exploring the timing, speed, and path of the projectiles shot at velocities 4, 8, and 100 were answered inconsistently by the members of Group 1. Although most of these subjects stated there was a relationship among the tick marks on the diagrammed paths, almost all thought that either one object or the other would land first. If they made that assertion, they were divided as to which velocity would produce the path of shortest duration. All agreed, however, that the length of the path increased with velocity.

Transformation. In this phase of the Protocol, subjects were asked at first to redraw the path of an object shot at velocity 4 and to mark the time intervals, as before. They were then shown a cardboard box and a stick figure, Mr. Observer. They were encouraged to use the stick figure and box as a model for the imaginary observer viewing the path of the object shot off the cliff in the earlier parts of the Protocol. The box represented the cliff. The stick figure represented the subject viewing the object from some distance at the side. They were then to think of this viewpoint as <u>View A</u>, the perspective from which they had been diagramming the path up to this time.

Several subjects in Group 1 still made errors in drawing the path of velocity 4: errors in placing the tick marks predominated, but errors in shape also occurred. Five subjects were still not making corrections to their diagrams after viewing the monitor.

After working with the redrawn View A of velocity 4, subjects were asked to draw what would be seen by Mr. O if he went behind the cliff (below the gun), and to place tick marks to represent time intervals. Having been shown what was meant by the directions through the use of Mr. O as a model, the subjects were asked to draw what the path would look like from that perspective. None of this group was successfully able to draw correctly the path which was labeled <u>View B</u>.

The next step was to represent what would be seen if the object shot at velocity 4 was viewed from the ground below, looking straight up. Mr. O was used to model the scenario. Neither was this viewpoint successfully represented by these subjects. Upon viewing the computer representations, subjects expressed recognition of the computer View B as correct, but they disagreed with computer View C. This part of the Protocol appeared frustrating to the subjects in Group 1. In the effort to consider the various viewpoints, they would physically orient their bodies and look in the new directions. Occasional remarks were made about not being able to draw the perspective, or the incorrect drawings would be scribbled over as if to manipulate the path drawn or show movement.

The sequence was repeated for the object shot at velocity 8. None from Group 1 successfully completed or corrected their drawings.

When asked to extrapolate, by drawing the three views of velocity 100, none of these subjects was able to draw the initial effort correctly, nor did they make corrections Later, when asked the series of questions--

(a) the observers' viewpoints, A, B, and C,

(b) perception of the length of the flight paths, and

(c) the landing time--none of these subjects was able to acknowledge that the observers, regardless of the perspective, saw the same object in the air at the same time, for the same duration, and the same length of path.

Part of the follow-up questioning included the exercise in interpolation. The subjects were asked to draw the object shot at velocity 4 from perspectives A, B, and C, but to indicate the location of the object if the time were stopped at tick 4. Group 1 subjects were unsuccessful at this exercise.

Post-Experimental Knowledge. When Group 1 subjects were asked to describe the effects of gravity on a dropped object and on a thrown object, they responded:

1. A dropped object would be pulled to the earth by gravity.
2. A thrown object would go out a distance, depending on its velocity, and then gravity would take over and pull it to earth.

Group 2: Pattern of Solution Responses

Group 2 contained the majority of subjects (26). This group, like the first, had difficulty integrating the horizontal and vertical components of the projectile motion. Where they differed from the first group was in their success at recognizing the discrepancies between their own representations and those generated by the computer. When they noted such discrepancies, they altered their representations. When they made changes, they usually applied the new representation(s) to subsequent related parts of the Protocol.

Pattern Matching. This is a part of the Flight Protocol in which Group 2 did well. When asked to diagram the path of the object shot at velocity 4, most of these subjects represented the path as a continuous downward curve with gradually increasing spaces between the tick marks (see Appendix B, Figure 24). They did this either before or after seeing the computer-generated diagram. Initial errors in representations were of the same type as described for Group 1. The prevailing initial error was in integrating the horizontal and vertical velocities.

When Group 2 subjects were asked to draw the path of the object shot at velocity 8, they tended, as a group, to do better at this task than they had done for the task of diagramming the path of the object shot at velocity 4. This indicated successful use of pattern matching as a problem solving strategy.

When questioned about the lengths of the paths of the objects shot at velocities 4 and 8, Group 2 subjects correctly identified the latter path. Extrapolation of the relationship between horizontal and vertical (gravity) velocities was not achieved by any of the subjects in this group. None of the subjects was able to represent the path of the object shot at velocity 100, but about one-third of them were able to redraw their diagram after seeing the representation done by the computer. Comments made by this group about computer representation of the path of the object shot at velocity 100 indicated that they agreed with what they saw but were still unsure about the curve of the line downward. When making the changes in the diagrams on their own papers, they would sometimes include the detailed pixel drops in the vertical decline as seen on the monitor (see Appendix B, Figure 25).

The questions which asked for a comparison of the relationship among the lengths of the paths of the objects shot at 4, 8, and 100 velocities drew inconsistent responses. All subjects in Group 2 recognized that there was a relationship among the tick marks of the paths of the three instances. What the relationship meant was not indicated by the subjects. They recognized that the object shot with velocity 100 had the longest of the three paths. But most of them thought the object shot with the velocity of 4 would land first. A few thought that the object with the greatest velocity would land first.

<u>Transformation</u>. <u>Transformation</u> was the part of the Protocol that required the subjects to diagram the path of the objects shot from three perspectives: (a) from the side (View A) as in the Pattern Matching phase, (b) from behind the cliff (View B), and (c) from below, looking up (View C). In order to help the subjects in this effort, they were provided with the opportunity to use the box as a model of a cliff and Mr. O, the stick figure, as the observer. They were already able to draw the paths of the objects shot at velocities 4 and 8, as demonstrated in the Pattern Matching phase of the Protocol. Most of them were also able to represent the path of the object shot at velocity 100.

If drawing the path of the projectile shot at various velocities involved the integration of complex variables (horizontal and vertical motion), then this part of the Protocol involved the decomposition of the integrated components. In other words, this part required analytical strategies where the salient features of the knowledge representation were to be extracted and operated upon.

Group 2 had very little success with this phase of the Protocol. In attempting to diagram View B or View C, the subjects expressed their difficulty and were observed to reposition their bodies and look in the new direction, displaying the same behavior as subjects in Group 1. Group 2 subjects, however, were usually able to diagram the alternate views after seeing the computer-generated diagrams. They reacted to what was presented, often disagreeing with the computer-representation, especially in the case of View C.

In responding to the direction to diagram the three viewpoints of the path of the object shot at 100 velocity, these subjects did not respond successfully. Many did copy the computer representation, but they seemed to do so with little discussion of its meaning.

None of Group 2 subjects, when asked about the relationship among the views of the various paths, acknowledged there was a relationship other than that the paths all represented an object shot off a cliff. There was no indication they recognized that the path of the object seen from three perspectives would be perceived to have the same duration in time and the same lengths. In fact, these subjects all gave inconsistent reports of the lengths of the paths of Views A, B, and C. Some said the longest path was seen from View A, some said View B, and some said View C. The responses to the questions about the time were also inconsistent both in terms of individuals and within the group. There appeared to be a guessing strategy rather than response based on the information presented. The interpolation exercise revealed that all of these subjects could successfully redraw the three viewpoints of the path of velocity 4, at tick 4. This confirmed the pattern matching ability of the Group 2 subjects.

Post-Experimental Knowledge. Group 2 subjects, like Group 1, correctly stated that a falling body was pulled to earth by the force of gravity. When asked about the effect of gravity on a thrown object, they, too generally, reverted to the intuitive notion that the horizontal velocity dominates at first, wanes, and then gravity takes over.

Group 3: Pattern of Solution Responses

Group three consisted of the smallest number of subjects, 5. These individuals, while they did not respond with 100% success, advanced the furthest through the Protocol. In almost every case, they were able to correct or verify their knowledge representations after viewing the computer representations. They were the most vocal in thinking aloud and interacting with the computer monitor.

Pattern Matching. All Group 3 subjects either diagrammed the paths of the objects at velocities 4 and 8 correctly the first time, or made corrections upon viewing the computer representation. What was notable was that any mistakes which were made had to do with the shape of the curve and not with the placement of the time intervals. This was different from the performance of the other two groups. Half of Group 3 subjects responded correctly to the question asking which of the two objects would land first, the one shot at velocity 4 or the one at velocity 8. They did acknowledge that the two would land at the same time. This group was able either to draw the velocity 100 example correctly at the first try or to correct the mistakes made after viewing the monitor. They freely discussed the apparent size limitations of the paper on which they were drawing; they attempted to show the proportion of velocity 100 correctly, upon consideration of the size of the diagrams of velocities 4 and 8. They also discussed the same size limitations of the monitor screen. There was not the same level of concern about the question of the descent of the object shot at velocity 100. The subjects acknowledged that it would come down in a gradually sloping path.

All but two subjects mentioned the relationship among the tick marks on the three paths as being parallel to the horizontal, when asked about the relationship among the tick marks on the three paths. Most of the subjects stated that the objects would all hit the ground at the same time, if shot at the same time.

Transformation. All Group 3 subjects were readily able to transfer the perspective of the path of the object shot at velocity 4; many were successful on their first try, and those who were not, were successful after viewing the computer representation. When asked to diagram the three perspectives of the path of the object shot at velocity 8, the subjects' representations were almost perfect. Like the members of the other two groups, Group 3 subjects would physically turn their heads and eyes as if to orient their bodies to the new direction while they were thinking; but they appeared to be comfortable with the task, rather than frustrated. Most of Group 3 had no difficulty in diagramming the path of the object shot at velocity 100, the extrapolation phase of the Protocol. In particular, one subject used

View A diagram as the basis for drawing View B and C, interpolating the points on the graph of View B from the points on the graph of View A, and likewise, the points on the graph of View C from the points on the graph of View A (see Appendix B, Figure 26).

Most of the subjects also thought that all three viewers would see the object land at the same time. All were uncertain about which perspective would appear to have the longest path. Interpolation of the data, by drawing the three perspectives of the path at velocity 4, tick 4, presented no difficulty to Group 3 subjects.

Post-Experimental Knowledge. All Group 3 subjects were able to articulate the effect of gravity on a dropped or thrown object. They responded without elaboration at this juncture, as if the answers they gave needed no discussion. All these subjects gave brief answers to the questions about the effect of gravity on a dropped or a thrown object. There was no apparent confusion about the relationship between the horizontal and vertical components of the projectile motion, whereas the confusion in this area of Groups 1 and 2 was evidenced in their responses.

Summary

When the raw GEFT scores were used to divide the total number of subjects into thirds--low, middle, and high--and the total scores graphed for inspection, the resulting curve was almost exponential in favor of the high GEFT scores.

The characterization of the knowledge representations of the subjects as they progressed through the increasingly demanding phases of the Flight Protocol revealed three patterns of responses. The response patterns organized the subjects into three groups: Group 1, Group 2, and Group 3.

Group 1 had the least success in moving through the Flight Protocol. The members of this group usually failed to correct their faulty knowledge representations, even after viewing the computer-generated representations.

Group 2 was particularly successful with the Pattern Matching phase of the Protocol and usually made corrections to any faulty knowledge representations. The members of this group, however, were largely unable to apply the new representations to generate the concept.

Group 3 was not only successful with the Pattern Matching phase but was also successful with the

Transformation phase and, in addition, was more successful in forming a concept of projectile motion that conformed with physical reality.

Although there were individuals in both groups, field dependent and independent, who did not succeed on any of the measures, the mean score on the total measure revealed that the field-independent subjects were likely to score twice as high as were the field-dependent subjects. The Transformation phase appeared to be the critical measure. Fifty percent of the field-independent subjects were successful in this measure, whereas only sixteen percent of the field-dependent subjects were successful.

During the Transformation measure, subjects were required to (a) decompose the knowledge representation of the projectile path into its vertical and horizontal components, and (b) diagram the resulting images. The information processing strategies employed in the effort to respond to this demand required mental operations of the sort that must be used during the Group Embedded Figures Test. In that instrument, the subjects find and trace a hidden figure after having viewed the figure alone for a short period. The subjects involved in the Flight Protocol had represented the vertical and horizontal components of the projectile path during the Intuitive Knowledge phase of the Protocol. In the Transformation phase, subjects may have been extracting the embedded figures of the horizontal and vertical components, just as they had done during the Group Embedded Figures Test. However, there appeared to be more than a simple perceptual activity occurring, for these subjects also applied the information presented to questions about the timing of the projectile flight. In addition, oral statements about the effect of gravity on a projectile indicated comprehension of the integration of the complex variables resulting in the curvature of the projectile path, regardless of velocity. Post-perceptual information processing must be taken into account to explain the difference between resultant learning evident in the field-independent group.

Conclusions

Mental models research attempts to describe explicitly the way people understand some domain of knowledge. Gentner and Stevens (1983) identified the applied usefulness of this research as in the simulation, teaching and testing for this knowledge. A simple physical system to be studied is selected so that it can be examined in detail. A dynamic system, such as projectile motion, is selected so that the change in state poses a problem to the subjects interacting with the system.

When Newell and Simon (1972) developed the program called the General Problem Solver (GPS), and described the computer as an analog for the human mind, they provided researchers with a fresh perspective for studying human cognition. The GPS worked in the following manner: (a) it identified the initial problem state; (b) it identified the final goal state; (c) it identified the difference that existed between the states; and (d) it applied an operation to eliminate the difference. The operation is a process of cognition.

The present study employed a Protocol that elicited from the subjects (a) their intuitive mental models of horizontal, vertical, and projectile motion, (b) their intermediate mental models of projectile motion, and (c) their post-experimental mental models of projectile motion. Information was provided to the subjects as they proceeded through the Protocol. It was provided in two ways: (a) as a pattern matching operation, and (b) as a transformation operation.

Pattern matching is assumed to be a simpler cognitive process than is transformation, involving perception of the difference between the initial problem state and the goal state, and information stored in short-term memory. In response to the questions asked by the Protocol, subjects diagrammed paths of projectiles, reducing the demand on short-term memory. Transformation, on the other hand, involved perceptual and post-perceptual mental processing. Not only did the subjects have to determine if the requested response "fit" the mental model (Minsky & Papert, 1969), but then the subjects had to decompose and reorganize the stored or perceived knowledge representation. The decomposition of the complex variables embedded in the diagrammed paths of the projectiles may have involved accessing the knowledge representations of horizontal and vertical paths stored in long-term memory. Facility with this type of processing is assumed to be characteristic of the subjects who are determined as relatively field independent.

Subjects in this study often revealed an erroneous intuitive concept of projectile motion in which the path of the object, regardless of velocity, tended to travel horizontally in a straight line before curving downward.

The velocity was related to the length of the horizontal path and to the time spent in the air. In general, subjects who were successful with the Transformation phase of the Protocol were better able to abandon their erroneous intuitive concept and acknowledge that gravity acted as a constant force on projectiles of all velocities, causing them to hit the ground at the same time if shot simultaneously.

Pascuale-Leone and Ribaupierre (1979), in their research on the attainment of Piagetian formal operations, found a relationship between the development of that cognitive level with field independence. This present study indicates that relatively field-independent adolescent subjects experienced greater success in solving problems presented during the Flight Protocol than did the relatively field-dependent adolescents. In particular, the field-independent group experienced more success during the Transformation phase of the Protocol than did the relatively field-dependent group.

This research extends the understanding of the novice problem solving activity in two ways:
(a) Cognitive style, namely, field-dependence-independence appears to be related to the cognitive process referred to in this Protocol as Transformation; and

(b) the success with the process called Transformation in this Protocol appears allied with overall success with the entire Protocol.

Educational Implications

Mental models research has been suggesting that teachers become aware of the intuitive knowledge representations that students bring to the instructional situation. This research has found that, in the case of projectile motion, the intuitive knowledge representation, though erroneous, tended to persist for some subjects after information to the contrary was graphically presented to the subjects on the computer monitor. Subjects often answered specific questions about a phenomenon correctly but failed to integrate the information into a conceptual whole. The information for some remained fragmented and unconnected, as indicated by the subjects in this study who successfully represented the path of a projectile without drawing the correct conclusion about the duration of the flight.

Cognitive style, namely, field-dependence-independence, is a perceptual quality that impacts on the kind of input received by a problem solver. In this research, a relationship between success on, Transformation, a particular operational phase of the Flight Protocol, and field-independence was uncovered. The kind of relationship is not revealed in this study, but it is evident that, for this specific Protocol, the group of subjects which was relatively field-independent had an advantage.

Teachers should heed the advice of the mental models researchers and, in the teaching of a new concept, engage the students in dialogue about their understanding of the concept and uncover the intuitive knowledge representations. They should probe understanding through questioning and recognize that presenting a lesson to students does not ensure understanding.

Future Research

The information uncovered in this study, about the successes of the field-independent group as compared with the field-dependent group, demands that further studies be designed for the purpose of uncovering the relationship between the transformation task and perceptual styles. The questions to be answered are: (a) During the transformation phase, are the subjects disembedding the complex variables, as they do the figures in the Group Embedded Figures Test, or are they isolating smaller details and reorganizing them?

(b) As a general rule, does cognitive style affect the quality of the information received from the computer monitor by the student?

These questions, if answered by future studies, could provide cognitive scientists and teachers with valuable insights into learning and, thus, aid in more efficient instruction.

BIBLIOGRAPHY

Anderson, N. H. (1981). Foundations of information integration theory. New York: Academy Press.

Burkhalter, B. B., & Schaer, B. B. (1984-85). The effect of cognitive style and cognitive learning in a nontraditional educational setting. Educational Research Quarterly, 9(4), 12-18.

DeKleer, J., & Brown, J. S. (1983). Assumptions and ambiguities in mechanistic mental models. In D. Genthner & A. Stevens (Eds.), Mental models (pp. 155-190). Hillsdale, NJ: Lawrence Erlbaum Associates.

DiSessa, A. A. (1983). Phenomenology and the evolution of intuition. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 15-33). Hillsdale, NJ: Lawrence Erlbaum Associates.

Duncker, K. (1945). On problem solving. Psychological Monograms, 58(5), Whole No. 207.

Ericsson, K. A., & Simon, H. A. (1984). Protocol analysis. Hillsdale, NJ: Lawrence Erlbaum Associates.

Eysenck, M. W. (1984). A handbook of cognitive psychology. Hillsdale, NJ: Lawrence Erlbaum Associates.

Furth, H. G. (1969). Piaget and knowledge. Englewood Cliffs, NJ: Prentice-Hall.

Gentner, D., & Gentner, D. R. (1983). Flowing waters or teaming crowds: Mental models of electricity. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 99-127). Hillsdale, NJ: Lawrence Erlbaum Associates.

Gentner, D., & Stevens, A. L. (Eds.). (1983). Mental models. Hillsdale, NJ: Lawrence Erlbaum Associates.

Good, R., & Smith, M. (1987, April). How do we make students better problem solvers? Science Teacher, 54(4), 31-36.

Haugeland, J. (1985). Artificial intelligence: The very idea. Cambridge, MA: MIT Press.

Johnson-Laird, P. N. (1983). Mental models. Cambridge, MA: Cambridge University Press.

Larkin, J. (1983). The role of problem presentation in physics. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 75-97). Hillsdale, NJ: Lawrence Erlbaum Associates.

Larkin, J., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. Cognitive Science, 11(1), 65-69.

Leeds, M. J. (1986). Mental models of learners about energy metabolism. Unpublished doctoral dissertation, Rutgers University, New Brunswick, New Jersey.

MacLeod, C. M., Jackson, R. A., & Palmer, J. (1986). On the relation between spatial ability and field dependence. Intelligence, 10(2), 141-145.

Mayer, R. E., & Fay, A. L. (1987). A chain of cognitive changes with learning to program in Logo. Journal of Educational Psychology, 79(3), 269-279.

McCloskey, M. (1983). Naive theories of motion. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 299-322). Hillsdale, NJ: Lawrence Erlbaum Associates.

McDermott, L. (1982). Problems in understanding physics (kinematics) among beginning college students--with implications for high school courses. In M. B. Rowe (Ed.), Education in the 80's: Science (pp. 106-128). Washington, DC: National Education Association.

Minsky, M., & Papert, S. (1969). Perceptrons. Cambridge, MA: MIT Press.

Newell, A., & Simon, H. A. (1972). Human problem solving. Englewood Cliffs, NJ: Prentice-Hall.

Norman, D. A. (1983). Some observations on mental models. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 7-14). Hillsdale, NJ: Lawrence Erlbaum Associates.

Pallrand, G. J. (1987a, April 23). Knowledge organization and representation in solving physics problems. Paper presented at the meeting of the National Association for research in Science Teaching (NARST), Washington, DC.

Pallrand, G. J. (1987b). Flight Protocol (rev. ed.) [Computer program]. Unpublished program. Rutgers, The State University, New Brunswick, New Jersey, Graduate School of Education.

Pascuale-Leone, J., & Ribaupierre, A. (1979). Formal operations and M power: A neo-Piagetian investigation. In D. Kuhn (Ed.), Intellectual development beyond childhood (pp. 1-43). Washington: Jossey-Bass.

Strawitz, B. M. (1984, November). Cognitive style and the acquisition and transfer of the ability to control variables. Journal of Research in Science Teaching, 21(8), 833-841.

Tuma, D., & Reif, F. (Eds.). (1982). Problem solving and comprehension. Philadelphia: Franklin Press.

Williams, M. D., Hollan, J. D., & Stevens, A. L. (1983). Human reasoning about a simple physical system. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 131-153). Hillsdale, NJ: Lawrence Erlbaum Associates.

Witkin, H. A., Moore, C. A., Oltman, P. K., Goodenough, D. R., Friedman, F., & Owen, D. R. (1977). A longitudinal study of the role of cognitive styles in academic evolution during the college years. GRE Board Research Report GREB No. 76-10R. Educational Testing Service.

Yager, R. E., & Yager, S. O. (1985, April). Changes in perception of science for third, seventh, and eleventh grade students. Journal of Research in Science Teaching 22(4), 347-358.

Young, R. M. (1983). Surrogates and mappings: Two kinds of conceptual models for interactive devices. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 35-52). Hillsdale, NJ: Lawrence Erlbaum Associates.

Ziman, J. (19^4). An introduction to science studies. New York: Cambridge University Press.

APPENDIX A

FLIGHT PROTOCOL

Flight Protocol

[The researcher asks the questions and makes the statements orally.
The student responds orally, or in written form when requested.]

I. Intuitive Knowledge
(establish background knowledge of the subject)

A. Vertical Motion

1. I am holding two balls. One is more massive than the other. I drop both from the same height at the same ti and there is no air resistance:

a. Which one hits the ground first?

b. What makes them fall?

c. What is the influence of gravity?

2. I drop one ball. Describe its speed as it falls.

3. Draw a diagram on your paper to show the path of one ball falling vertically. A clock is ticking. On the diagram, show me where the ball is at zero tick, one tick, two ticks ....

B. Horizontal Motion

1. I roll a ball across the floor--a smooth glassy floor. Describe the speed.

2. Draw a diagram on your paper to show the path of the rolling ball. Mark your diagram to show time intervals: use <u>tick</u> marks. (Be sure the subject assumes zero friction after the ball leaves the hand.)

C. Computer Representation

1. We will now look at the computer screen and check to see how the computer diagrams the path of the falling ball (see Figure 1), and the .ling ball (see Figure 2).

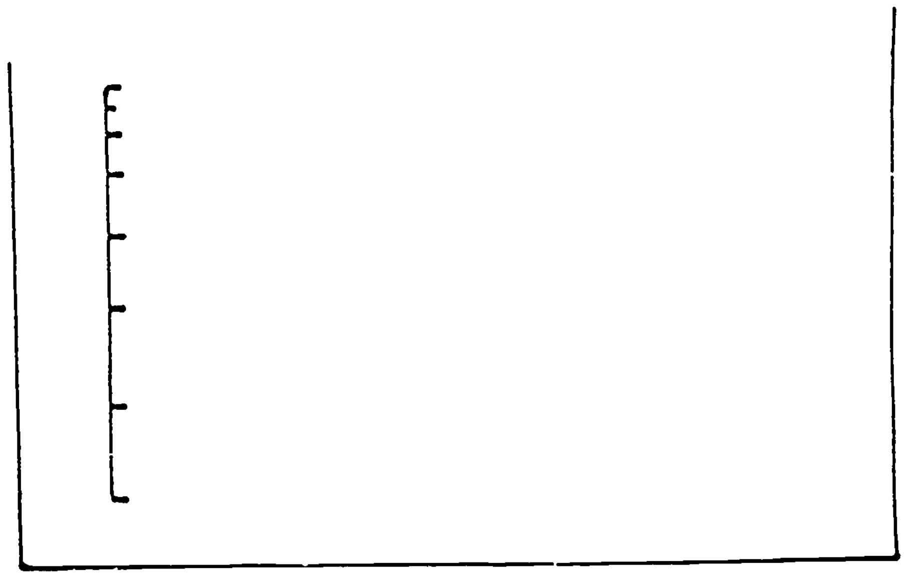

Figure 1. Computer representation of the falling ball.

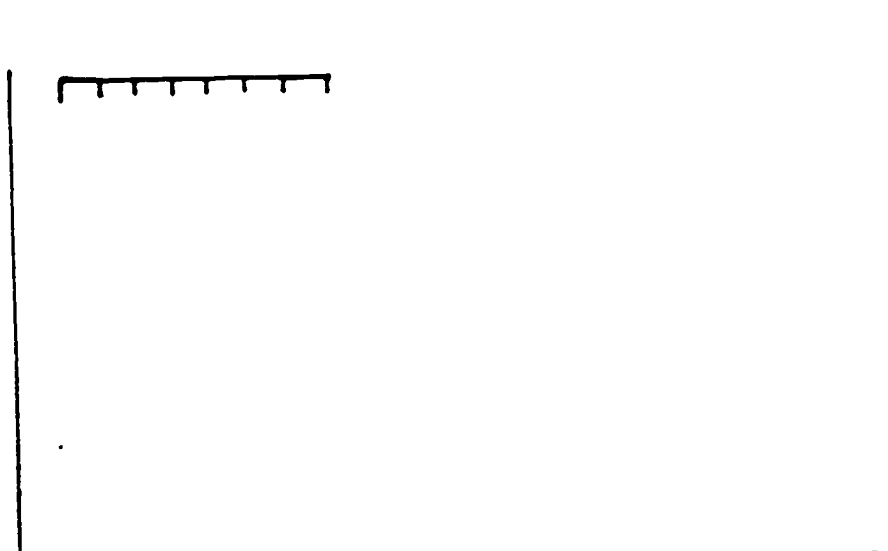

Figure 2. Computer representation of the rolling ball.

2. How does the computer representation of the falling ball compare with your diagram? (What about the overall pattern? The details?)

3. How does the computer representation of the rolling ball compare with your diagram? (What about the overall pattern? The details?)

4. You may fix your diagrams if you wish.

D. Projectile Motion

1. I stand on a cliff and shoot a ball off it. What does the diagram of its path look like when seen from the side: View A?

2. Draw a diagram on your paper to show the path of the ball. Mark your diagram to show time intervals: use tick marks. (Tick, tick, tick, tick ....)

E. Computer Representation

1. Let's see how the computer diagrams the path of an object shot from a cliff (see Figure 3).

2. How does your diagram compare with the computer diagram? (What about the overall pattern? The details?)

II. Pattern Matching
(Vary the horizontal velocity of the projectile.)

1. I stand on a cliff and shoot a ball off it. What does the diagram of its path look like (seen from the side) at a low velocity, say 4? Draw a diagram of the path and show the tick marks.

2. How does the computer representation (see Figure 4) compare with your diagram? (What about the overall pattern? The details?)

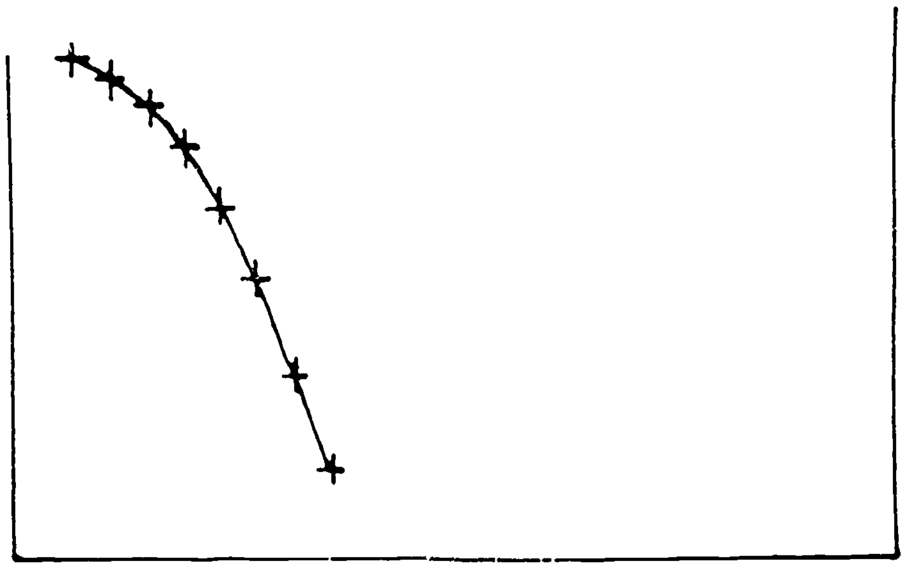

Figure 3. Computer representation of an object shot from a cliff (View A).

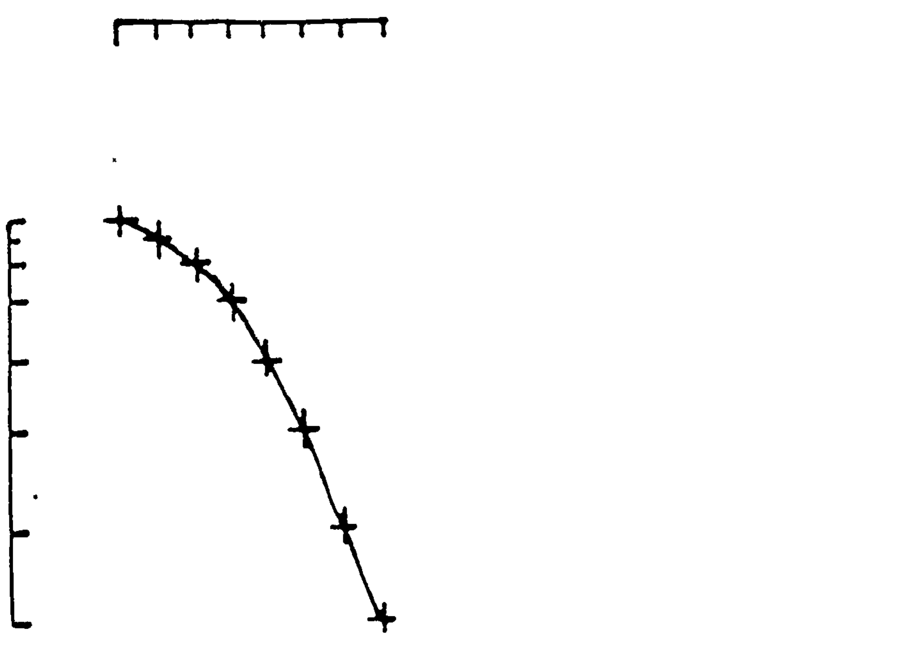

Figure 4. Computer representation of a ball shot from a cliff at a velocity of 4.

3. Now draw the path of an object shot at a velocity of 8. Show the tick marks.

4. How does the computer diagram (see Figure 5) represent it?
   Does it look like your diagram?
   (What about the overall pattern? The details?)

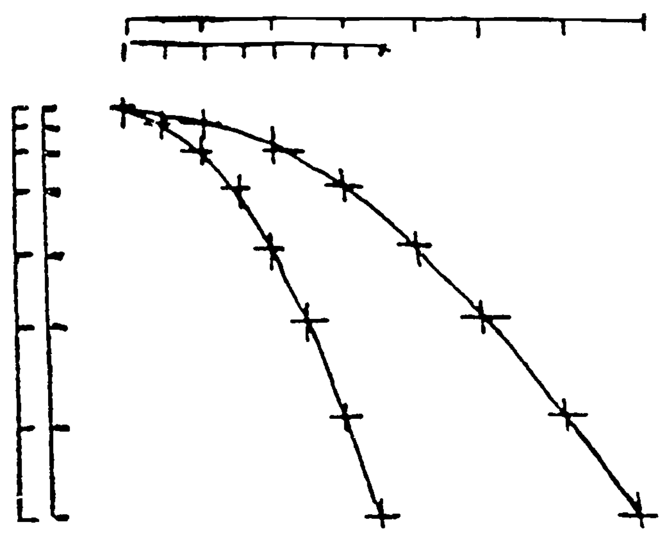

Figure 5. Computer representation of balls shot from a cliff at velocities of 4 and 8.

5. Is there any relationship between the path of an object shot at a velocity of 4 and the path of an object shot at a velocity of 8?

6. If two objects are shot at the same time, one with a velocity of 4 and one with a velocity of 8:

   a. Which has the longer path?

   b. Which hits the ground first?

7. An object is shot at a high velocity, say 100. Diagram its path. Put tick marks on the diagram.

8. How does the computer representation (see Figure 6) compare with your diagrams? (What about the overall pattern? The details?)

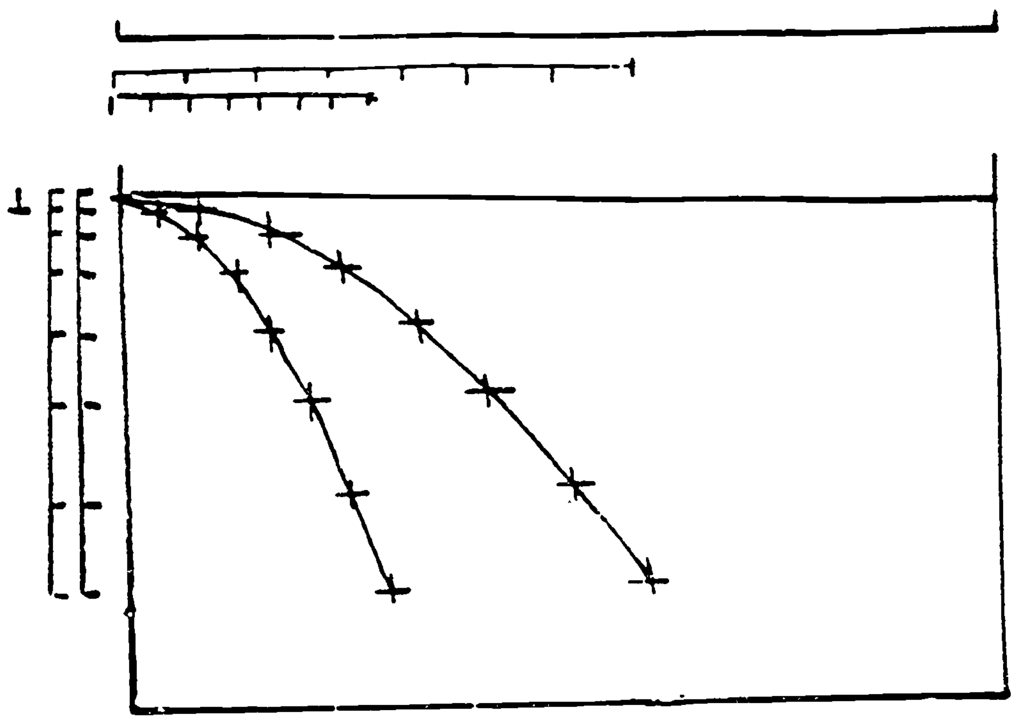

Figure 6. Computer representation of objects shot from a cliff at velocities of 4, 8, and 100.

9. Is there any relationship among the diagrams of velocity 4, 8, and 100? Is there any relationship among the tick marks?

10. After seeing the computer representation, would you change your diagrams of the paths of the objects shot at velocities 4, 8, or 100?

11. Assume that three objects are shot off the cliff at the same instant but at three velocities: 4, 8, and 100.

    a. Which has the longest path?

    b. Which hits the ground first?

12. If an observer, standing on the ground in the dark, hears two objects hit the ground at the same time--one hits in front of the observer (closer to the cliff) and one hits behind (farther from the cliff):

    a. Were the objects shot at the same time?

    b. Were the objects shot with the same velocity?

III. Transformation
(Vary the position of the observer and the velocity of the object.)

1. Once again, draw the path of an object shot from a cliff at a velocity of 4 (View A). Put the tick marks on it.

2. [The researcher demonstrates using a box containing a stick figure, Mr. O.]

   Now imagine that Mr. O stands behind the cliff and can see the path of the object clearly. Diagram what Mr. O sees (View B). Put tick marks on your diagram.

3. [The researcher demonstrates using a box containing a stick figure, Mr. O.]

   Now imagine that Mr. O lies on the ground surface looking up at the path of the object shot from the cliff. Diagram what Mr. O sees (View C). Put tick marks on your diagram.

4. How does the computer representation (see Figure 7) compare with the paths you have drawn? Would you alter your diagrams now that you have seen the computer diagrams?

5. (Repeat section III, # 1-4 for a velocity of 8. Show Figure 8.)

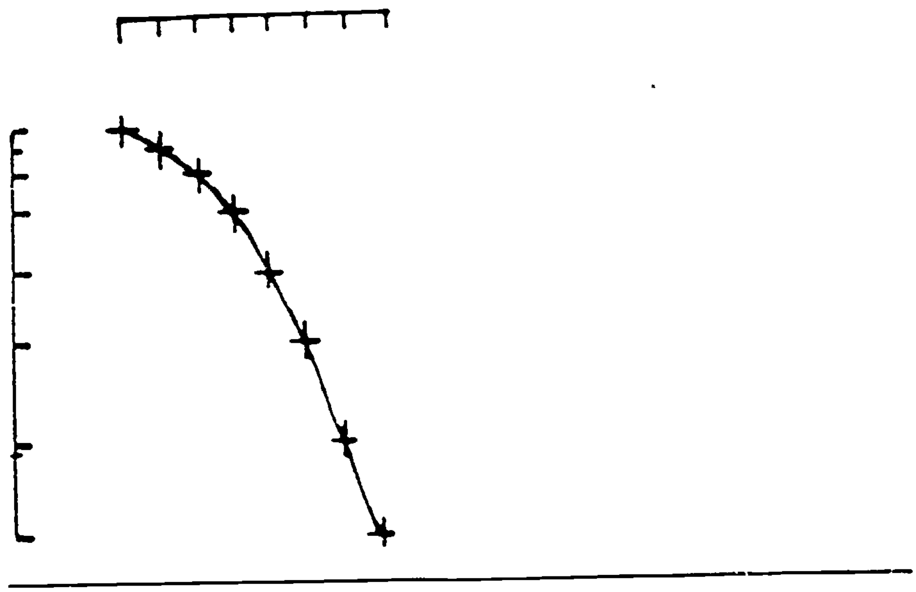

Figure 7. Computer representation of the motion of the object with a velocity of 4, as perceived by the three observers.

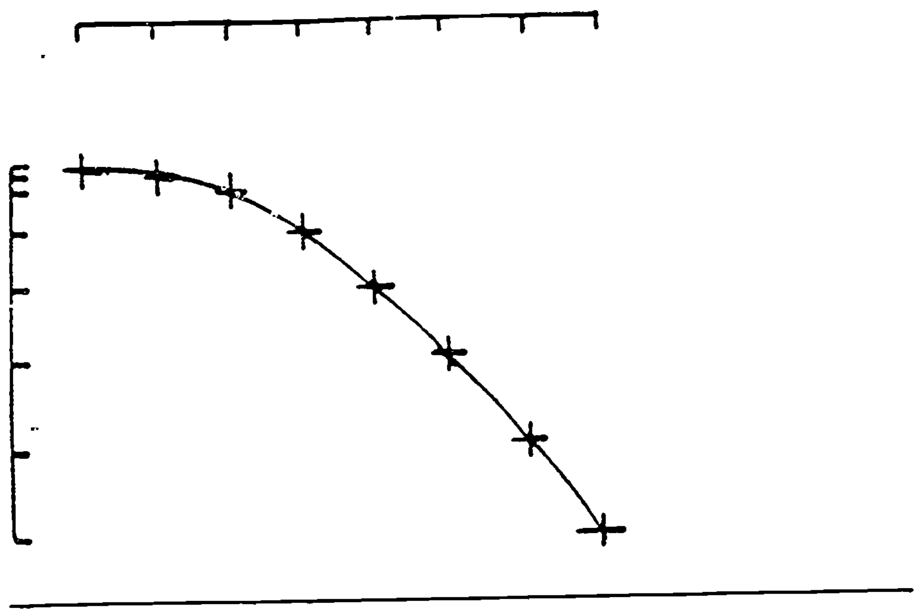

Figure 8. Computer representation of the motion of the object with a velocity of 8, as perceived by the three observers.

6. Imagine that observers A, B, and C are able to talk to each other by phone. Each observer sees the same object at the same instant.

   a. Which observer thinks he/she sees the longest path?

   b. Which observer thinks he/she is the first to see the object hitting the ground?

   c. Is there any relationship among what the three observers report? Describe the relationship.

7. (Repeat section III, # 1-4 for a velocity of 100. Show Figure 9.)

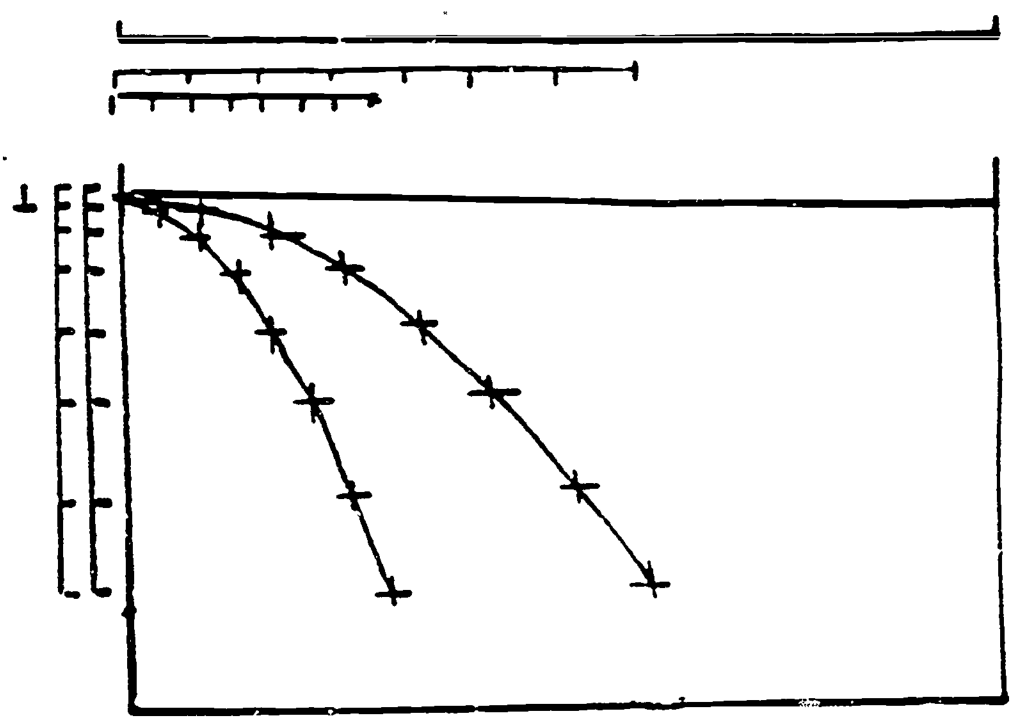

Figure 9. Computer representation of the motion of the object with velocities of 4, 8, and 100, as perceived by the three observers.

8. After a time interval of 4, how would observer A diagram the path and position of an object shot at velocity 4?

9. After a time interval of 4, how would observer B diagram the path and position of the object shot at velocity 4?

10. After a time interval of 4, how would observer C diagram the path and position of the object shot at velocity 4?

11. Compare your diagrams with the computer representation (see Figure 10). If you wish, you may change your diagrams.

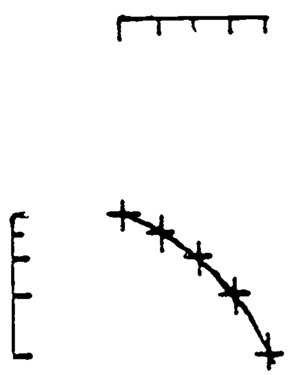

Figure 10. Computer representation of the motion of the object after an interval of 4 and a velocity of 4, as perceived by the three observers.

IV. Post-Experimental Knowledge

A. What is the effect of gravity on a falling object?

B. What is the effect of gravity on a thrown object?

APPENDIX B

FIGURES 11 THROUGH 26

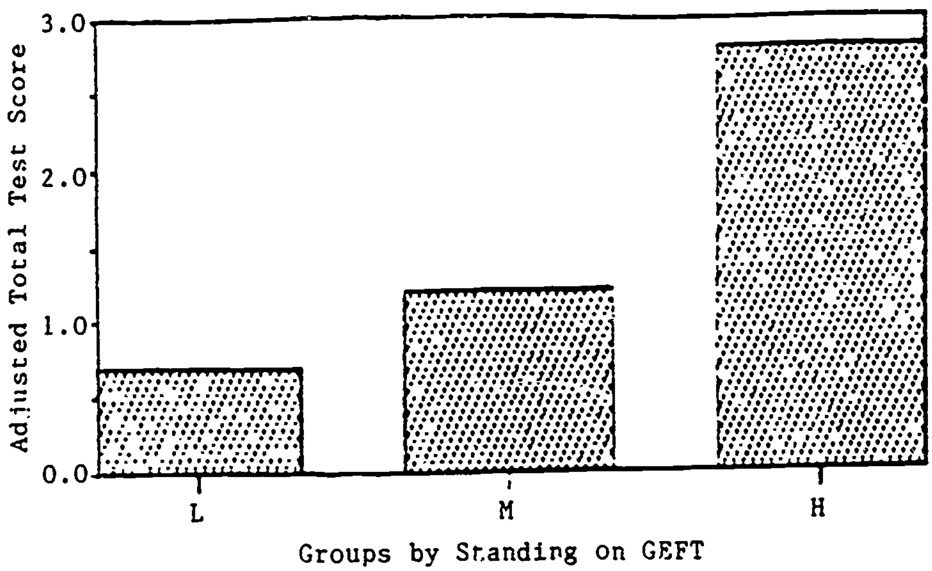

Figure 11. Mean total score on Flight Protocol compared with grouped GEFT scores.

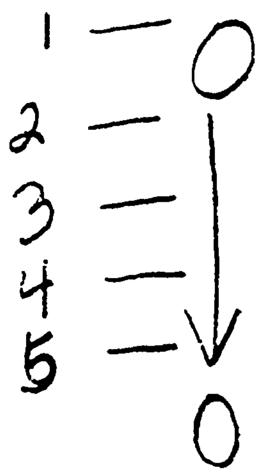

Figure 12. Vertical path showing even spacing of tick marks. (Intuitive)

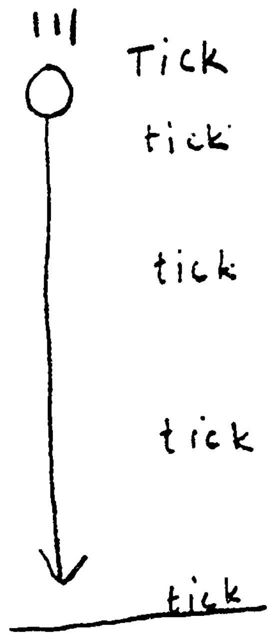

Figure 13. Vertical path showing increasing spacing of tick marks. (Intuitive)

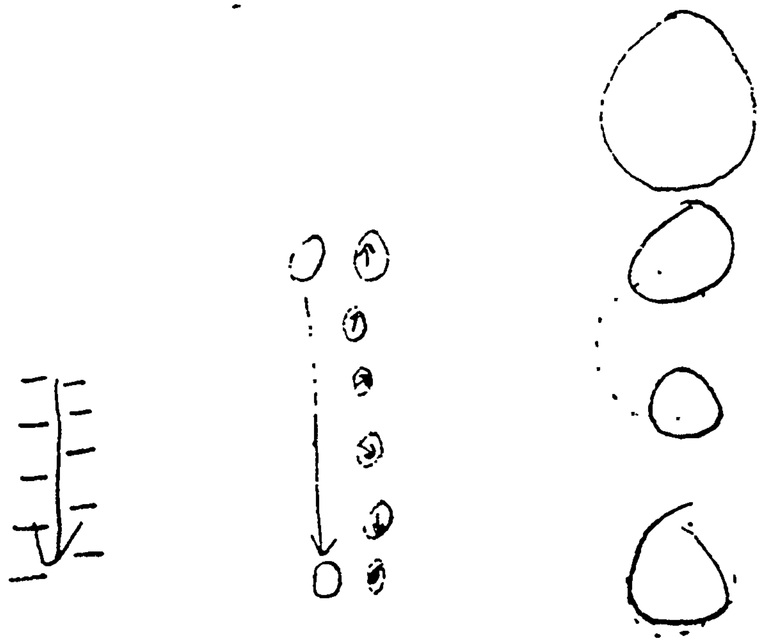

Figure 14. Vertical paths showing different types of changes made. (Intuitive)

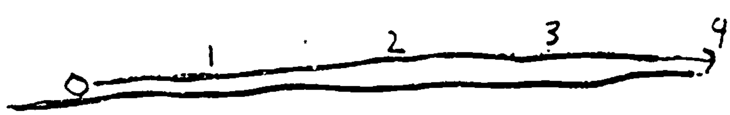

Figure 15. Horizontal path showing even spacing of ticks. (Intuitive)

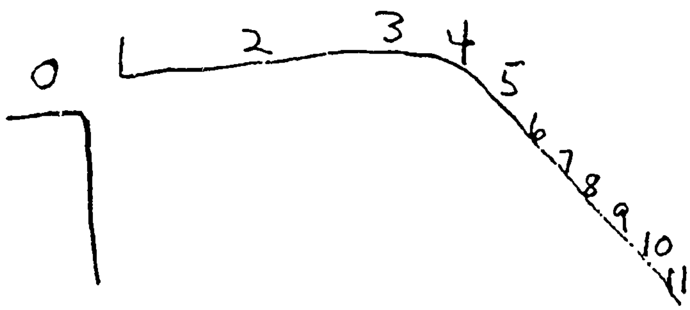

Figure 16. Projectile path showing a decrease in interval spacing from top to bottom. (Intuitive)

Figure 17: Projectile path showing vertically straight component. (Intuitive)

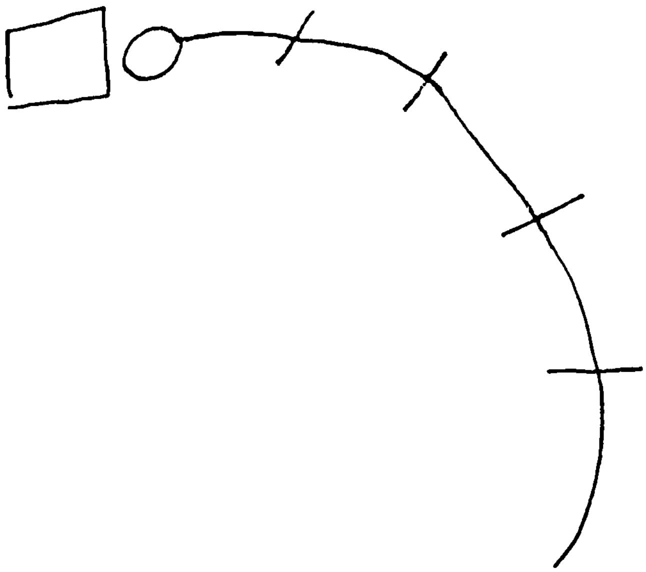

Figure 18. Projectile path showing flat horizontal component and even spacing of tick marks. (Intuitive)

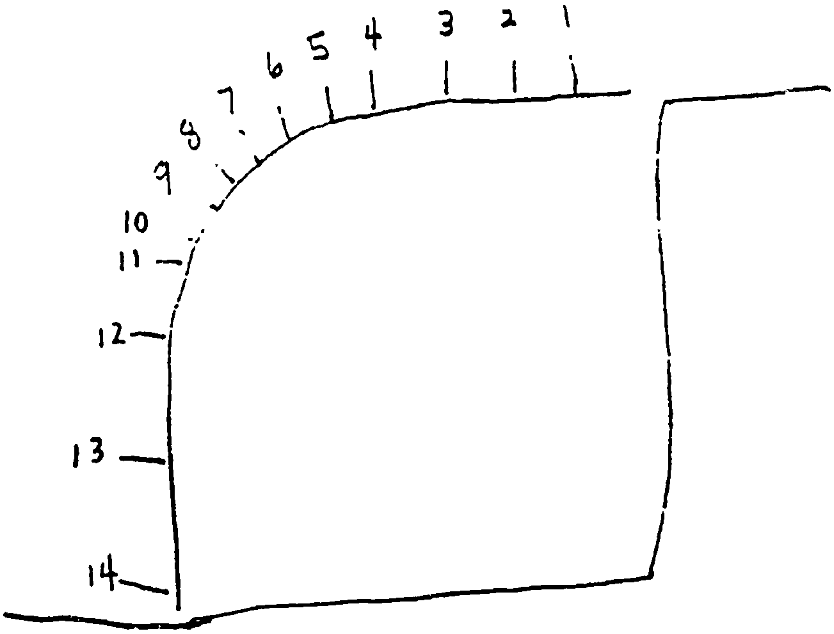

Figure 19. Projectile path showing flat horizontal component and decreasing spacing of tick marks at the curve. (Intuitive)

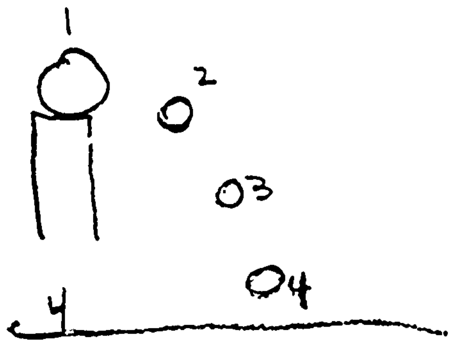

Figure 20. Projectile path showing regular spacing of tick marks, as done by Group 1 subject.

Figure 21. Projectile path showing decreasing tick intervals, as done by Group 1 subject.

Figure 22. Projectile path showing changing interval pattern, as done by Group 1 subject.

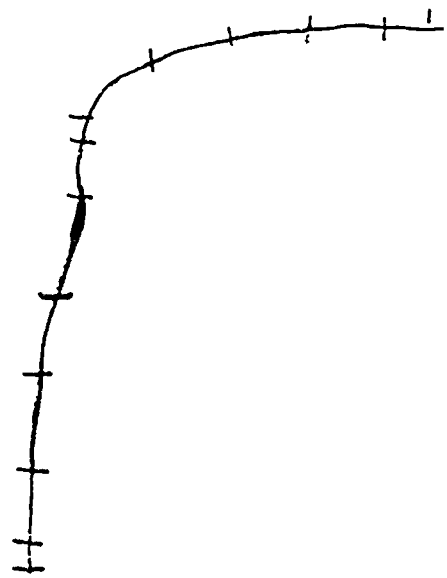

Figure 23. Projectile path showing no obvious pattern of intervals, as done by Group 1 subject.

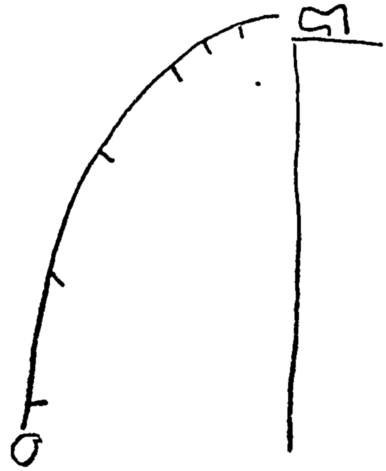

Figure 24. Projectile path showing increasing intervals, as done by Group 2 subject.

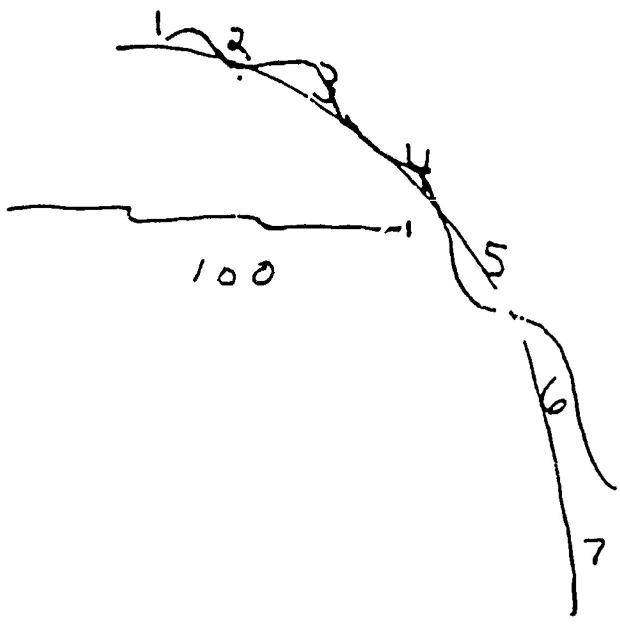

Figure 25. Corrected diagram of velocity 100 projectile, as done by Group 2 subject.

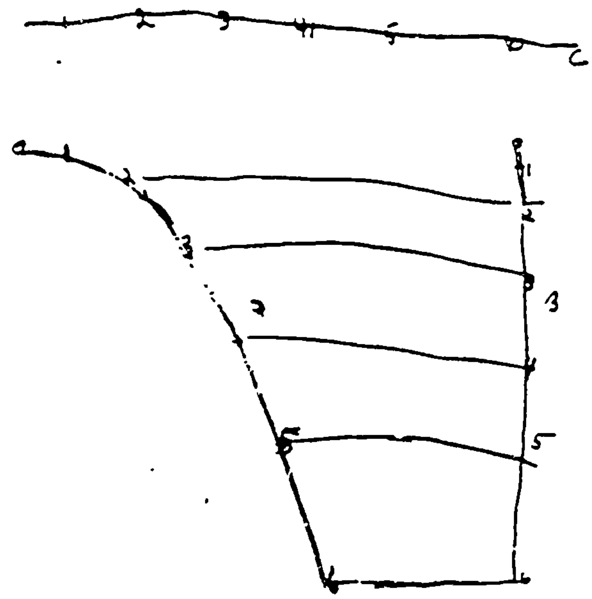

Figure 26. Diagrams of Views A, B, and C, as done by Group 3 subject.