Microcomputer-Based Diagnosis and Remediation of Simple Aristotelian Alternative Conceptions of Force and Motion

by

Herman G. Weller

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Approved:

Norman R. Dodl, Chairman

John K. Burton

George E. Glasson

James W. Garrison

H. Rex Hartson

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Committee Chairman: Norman R. Dodl
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(Abstract)

Science students often bring naive models of the natural world to the classroom which can be resistant to traditional methods of teaching. If both the teacher and the student are unable to detect and change these conceptions, the student's ability to learn may be seriously impeded. A solution to this instructional dilemma would be to devise a method which a teacher could use to determine whether such naive models, or *alternative conceptions*, are held by a student and, if so, help the student to develop a plausible conception more in line with the current scientific viewpoint to replace each alternative conception. This is a report on the investigation of such a method: a microcomputer-based system for the diagnosis and remediation of three Aristotelian alternative conceptions of force and motion held by 8th-grade physical science students.

The present investigation employed a microcomputer-displayed, graphics-based system to select students for possession of alternative conceptions and to posttest following remedial instruction. When alternative conceptions were detected, the system presented two simulations which were designed to facilitate the student's alteration of one or more of these naive conceptions. The instructional strategies incorporated into the computer simulations were consistent with a theory of instructionally-elicited conceptual

change which: a) facilitated the student's recognition and discovery of a phenomenon which was anomalous to his or her conceptual framework and which epitomized the relevant scientific concept, and b) allowed the student to manipulate the objects and relationships of the phenomenon, experiencing the consequences of that action, so that the student would gradually adjust his or her conceptual categories until the phenomenon became anticipated.

Students who had completed the study of force and motion (*completed* students) exhibited a very different pattern of non-scientific answers on the computer diagnostic test than did students currently studying that topic (*in-process* students). The *completed* students who were selected for possession of alternative conceptions were facilitated by the computer simulations in altering their naive conceptions to a significant degree. The computer posttest supplied evidence of the students' short-term conceptual change, and the Retention Test 1.5 months later supplied evidence of robustness of the change.

Acknowledgments

This dissertation is about teaching and learning. The actual dissertation volume will probably be remembered in a few years as merely a bound, rectangular marker placed along the path of my multi-decade journey through the fascinating fields of teaching and learning. The document is important to me because it represents a 47th-year checkup on my processes of learning and teaching during that lifelong journey. It is time, at this point in the processes to pause, look backward along the path, and thank those from whom I have learned the most. My gratitude will go forever to the Master Teacher, the one instructor who has never ceased walking along the path with me and educating me, even during the times when I have stopped listening to Him.

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Chapter 1

INTRODUCTION

Science students often bring naive models of the natural world to the classroom which can be resistant to traditional methods of teaching. If both the teacher and the student are unable to detect and change these conceptions, the ability of the student to learn may be seriously impeded. A solution to this instructional dilemma would be to devise a method which a teacher could use to determine whether such naive models, or *alternative conceptions*, are held by a student and, if so, help the student to develop a plausible conception more in line with the contemporary scientific viewpoint to replace each alternative conception. Such a method should be efficient in the sense that it should not require the addition of considerable time and effort to the burden of the typically overworked science teacher; nor should it require the purchase of various sets of specialized laboratory apparatus designed for treating each different alternative conception. This is a report on the investigation of such a method: a microcomputer-based system for the diagnosis and remediation of three Aristotelian alternative conceptions held by 8th-grade physical science students. These three conceptions are contrary to the Newtonian system of mechanics which is taught in physical science (and which is, in fact, also taught in high school physics and university freshman physics):

1) *Quickness of fall depends on mass* conception

With no air resistance, the downward movement of a more massive object is faster than that of a less massive object.

2) *Unbalanced force* conception

If an object is moving and no unbalanced force is acting on it, the object will come to rest.

3) *Direction of vertical movement depends on type of material* conception

a) Light objects rise because they are made of material which naturally tends to move upward; b) heavy objects fall because they are made of material which naturally tends to move downward.

Traditionally, when the teacher has not recognized that a student possesses an alternative conception, science instruction may interact with the naive conception in unpredictable (and often unsuspected) ways leaving the student's alternative conception either undisturbed or co-existing with the new science conceptions (Hewson, 1981). This can be detrimental to the science learning of the student and inefficient for the science teacher. Later concepts depend upon the student possessing the scientifically accepted version of the initial alternative conception.

The present investigation employed a microcomputer-displayed, graphics-based system to pretest for the student's possession of any of the above three alternative conceptions of force and motion and to posttest following remedial instruction. When alternative conceptions were detected, the system presented two simulations which were designed to facilitate the student's alteration of one or more of these alternative conceptions according to the author's theory for instructionally fostering conceptual change. The simulations, termed the Objects Falling simulation and the Cube Moving simulation, are described in detail in the section on *Computer simulations* in chapter 3 on *Methodology*.

Background

For many students, science is a very difficult subject to learn. A significant portion of a student's prior knowledge, which has been derived from the world of everyday practical experience, is incompatible with that taught in science classes. For two decades, evidence has been accumulating that a significant proportion of science students of all ages, weak as well as strong learners, possess alternative conceptions (Driver & Easley, 1978; Hasweh, 1988; Osborne & Freyberg, 1985; Resnick, 1983). These alternative views of the world, which have been derived from the individual's previous experiences, often continue despite several years of traditional instruction in concepts which are more aligned with the scientist's viewpoint and which contradict the naive conceptions. In many cases, there is a regularity to these naive models of the natural world across different students (Hasweh, 1988).

Two examples of alternative conceptions drawn from studies of physics students' beliefs about force or motion may serve to illustrate the central idea of alternative conceptions: (a) Force is an intrinsic quantity of a moving object in the direction of motion (Viennot, 1979), and (b) when comparing the motion of two balls as one overtakes and passes the other, the balls have the same velocity when they are next to each other (Trowbridge & McDermott, 1980).

To the science teacher's chagrin, the world of force and motion (i.e., dynamics) in everyday experience is largely an Aristotelian world (Garrison & Bentley, 1990). Heavier objects do fall faster than lighter ones through material media (e.g., a stone and a feather falling through the air). Where friction is present (often unrecognized as a force by the beginner), one must push on an object to keep it in motion. For many students the *network of idealizations* which is physical science (where the natural world is explained by referring it to mathematical formulae, and any two objects fall with the same acceleration and moving objects do not require a continuing force to keep them in motion) is indeed an alien world with an alien language.

In the area of dynamics, it has been found that many alternative conceptions are similar in some aspects to historical explanations (Hasweh, 1988). The two historical theories which present-day naive conceptions of dynamics have been found to resemble most often are the *impetus theory of motion* and the *Aristotelian theory of motion*. Alternative conception (a) above is similar to the *impetus theory of motion* of the Middle Ages which proposed that when a force acts on an object it imparts an impetus to it that keeps it in motion after the original force stops acting on the object (McCloskey, 1983). This theory explained the observation that most moving objects eventually come to rest, by assuming that the impetus then dissipates gradually, either spontaneously or due to external forces such as air resistance.

On the other hand, the *Aristotelian theory of motion* of the 4th century B.C. postulated that objects cannot move without direct contact with their movers (i.e., without the influence of a force). Aristotle explained the motion of objects which continue to move after the applied force is discontinued (such as that of projectiles) by postulating intermediate moving agents, like air currents that move backward from the front of the projectile and push the rear of the object forward (Hasweh, 1988).

Naive conceptions which resemble the Aristotelian view of motion have been the most often investigated. For example, in a study of elementary school children, diSessa (1982) found that most of them held the Aristotelian notion that objects already in motion move in the direction one pushes them. Because Aristotelian alternative conceptions have been the most frequently studied, they will be utilized in the present investigation.

It is in the physical (or general) science course in the 8th or 9th grade that many students first encounter extensive formal instruction which contradicts several of their naive conceptions of force and motion. Despite the instruction there and in the ensuing grades, the same alternative conceptions are also held by secondary and university students. For example, Champagne, Klopfer and Anderson (1980) found that most of the college students they surveyed believed that objects fall at a constant speed, a speed which the students thought (as did Aristotle) to be proportional to the weights of the objects.

The 8th-grade confrontations between students' naive beliefs about dynamics and instruction on the scientific viewpoint have significant importance for the children's future science learning. Therefore, the present investigation will concentrate on fostering conceptual change of 8th-graders who are found to hold one or more of the above three alternative conceptions several weeks after their physical science classes have covered force and motion.

Hasweh (1988) has argued that a conceptual-change study should utilize a specified, appropriate theory of conceptual change, proposing and implementing instructional strategies in order to test the theory. He has contended that many studies of students' conceptions (e.g., studies of motion by Champagne, Klopfer, & Anderson, 1980; Clement, 1982; Viennot, 1978) have included propositions for certain instructional strategies which, although appearing to be promising for inducing conceptual change, have not been based on an explicit and adequate theory or explanation of conceptual change.

The author has constructed a theory for instructionally eliciting a student's conceptual change in science. This theory proposes that the science student who possesses an alternative conception can be facilitated in discovering a phenomenon which is anomalous to his or her conceptual framework, and which epitomizes the relevant scientific concept. This facilitation involves allowing the student to examine the phenomenon repeatedly, in effect *playing* with exemplars of the scientific concept by acting upon the objects and relationships of the phenomenon, and then experiencing the consequences of that action. The result is that the student will gradually adjust his or her conceptual categories in a complex manner until the phenomenon becomes anticipated. The author has detailed the *stages of the student's discovery*, the *characteristics of the student's discovery*, and the necessary *characteristics of the instructional situation* which presents the anomalous phenomenon to the student.

For the construction of this conceptual change theory, the author has drawn heavily upon: 1) the theoretical views of Thomas Kuhn on the role of anomaly in the discovery of a new and unsuspected phenomenon (Kuhn, 1962), and on the function of thought experiments in science (Kuhn, 1977); and 2) the thoughts of John Dewey (1916) on the relation of experience to thinking. Although drawing heavily on the thoughts of these two men, the author has compared their ideas judiciously with the observations which he himself has garnered during twelve years of teaching various physical science courses in Grades 8-12.

The author's conceptual change theory has drawn also upon: a) the model for the facilitation of conceptual change in science that was proposed by Posner, Strike, Hewson and Gertzog (1982); and b) the criticism of the latter model by Garrison and Bentley (1990) for its assumption that a student's learning is a *rational* activity, and for ignoring *pre-rational* considerations in learning. Garrison and Bentley have maintained that the student learns science much as one learns a language, by "playing the game of language--or science," that is, by encountering such exemplars of science situations as free fall in a near vacuum and motion along nearly frictionless surfaces via the concrete problem-solutions of the scientist.

Consistent with the author's theory for instructionally eliciting a student's conceptual change in science, the computer simulations in the present study have been designed to present environments which will foster conceptual change by each selected student by: (a) presenting a phenomenon which is anomalous to the student's conceptual framework, causing the student to be dissatisfied with his or her naive conception, (b) allowing the student to *play the game of science* by encountering exemplars of free fall in a vacuum and motion with all the forces shown, and (c) facilitating the student's adjustment of his or her conceptual categories until the phenomenon becomes anticipated. The following two hypotheses were used as the basis of the present study.

Hypothesis # 1.

> **Working through the two simulations in the remedial portion of the microcomputer program will enable the 8th-grade physical science students who possess one or more of the above three Aristotelian alternative conceptions to change them to the appropriate *more scientifically acceptable* (i.e., Newtonian) conceptions.**

To prepare 8th-grade students adequately for their future science learning, a diagnosis-and-remediation system for alternative conceptions should induce conceptual changes which are robust over time. Little research has been conducted on the robustness of conceptual change fostered by instructional intervention. In a study of the diagnosis and remediation of a *position criterion* for judging when two objects have equal velocities (i.e., alternative conception (b) on page 7), Hewson (1985) has found that the new conception persisted at least six months after intervention. Similarly, in the present study instructional strategies were incorporated into the two simulations in order to foster conceptual change which persisted over time. The second hypothesis was.

Hypothesis # 2.

Working through the two simulations in the remedial portion of the microcomputer program will enable the 8th-grade physical science students who possess one or more of the above three alternative conceptions to retain changes in them over the long term. That is, 1.50 months after initially using the diagnosis-and-remediation system, most of a 25% sample of experimental group students will employ the same scientific answers to PostTest questions with which they had replaced nonscientific answers to Selection Test questions.

Chapter 2

REVIEW OF LITERATURE

Alternative conceptions in science

During the past twenty years, there has been a growing awareness among science educators of the importance of the conceptions which children of all ages bring with them to science lessons. Ausubel (1968, p. 209) has contended that children acquire from extensive personal experience many naive concepts about their physical and biological environment; views of the world which differ from the scientist's viewpoint and which tend to persist and to compete with more mature conceptions. The scientist's view, where the natural world is explained by referring it to idealized and mathematized formulae which are then thought to determine it (Garrison, 1986), is indeed alien to most students.

Recent research (e.g., reviewed by Driver & Easley, 1978; Hasweh, 1988; Osborne & Freyberg, 1985) has not only confirmed Ausubel's contention, but has also shown that these naive ideas of children are not isolated notions, but rather are components of alternative conceptual structures which provide a reasonable and coherent understanding of the world from the child's point of view (Champagne, Klopfer, & Anderson, 1980). The robustness over time of these intuitive conceptual structures has been demonstrated by recent findings that they are also possessed by some older students who have had a great deal of exposure to science teaching (Hasweh, 1988).

Increasingly, one hears a call from researchers in science teaching for a change in approach that will take into account the naive conceptions of the students. For example, Pope and Gilbert (1983) have suggested that a "cultural transmission" approach to teaching and knowledge have dominated science education, where the students are perceived as the passive receivers of information rather than active participants, and with the consequent neglect of the role of the students' personal experiences in their construction of knowledge. Pope and Gilbert have contended that few science teachers recognize and use the personal experiences and spontaneous reasoning of their pupils.

Osborne and Wittrock (1983) have called for a considerable emphasis in research, curriculum design, and teaching at all levels on the nature and detail of children's views of the world and their meanings for words used in science. They have maintained that teaching should take student perceptions and viewpoints fully into account and, where appropriate, attempt to alter or build upon children's ideas.

In such exhortations of science educators to take students' naive conceptions into account, one hears echoes of the voices of Dewey and Whitehead of sixty or more years past. In particular, it was Dewey (1916) who advised that we teach using the *chronological* method ". . . which begins with the experience of the learner and develops from that the proper modes of scientific treatment." He realized that although the science teacher will have to spend more time using this method than with authoritarian presentation, the "apparent loss of time involved is more than made up for by the superior understanding and vital interest secured. What the pupil learns he at least understands."

It was Whitehead (1929) who admonished science teachers that "The child should make them [the main ideas of science] his own, and should understand their application here and now in the circumstances of his actual life." In even stronger words, he added that " . . . ideas which are not utilized are positively harmful. By utilizing an idea, I mean relating it to that stream, compounded of sense perceptions, feelings, hopes, desires, and of mental activities adjusting thought to thought, which forms our life."

The *cognitive overthrow* by the student of his alternative conceptual structure in order to shift to a framework consistent with the scientist's viewpoint, has been viewed by several investigators (e.g., Posner, Strike, Hewson, & Gertzog, 1982) as similar to the historical paradigm shifts of the scientific community as described by Kuhn (1962). In this view, in order to alter the alternative conception the student must pass through a transition phase during which the mismatch between the naive conception and the scientific conception becomes so evident that it causes a state of *cognitive conflict* (or *mental disequilibrium*).

The description of conceptual change as cognitive overthrow is consistent with a view of learning as an "ongoing construction of meaning," a view which has emerged over the past decade and is termed a *neoconstructivist* view by some researchers (e.g., Pope & Gilbert, 1983; Trowbridge & Mintzes, 1988) or a *radical constructivist* one by others (e.g., Von Glasersfeld, 1988). Models of the neoconstructivist type propose that understanding requires vigorous participation of the learner in reordering his or her experience in light of previously-learned knowledge. Learning demands the active retrieval of knowledge from long-term memory; generation of meaning from sensory data by applying information-processing skills; and organization, coding, and storage of new meanings in long-term memory (Trowbridge & Mintzes, 1988).

For example, in the neoconstructivist "generative learning" model of Osborne and Wittrock (1983), the brain ignores some information from experience and selectively attends to other aspects. This selective attention is based on the stored memories and information processing strategies of the brain. Meaningful learning occurs through *generation* (i.e., active construction) of meaning, by linking sensory information with the aspects of stored memory that are considered relevant. The new meanings are tested further against sensed experiences as well as against the logic of relevant aspects of long-term memory. The student's motivation depends on his or her acceptance of a major responsibility for learning--for constructing meaning and testing these constructions against experience and structures in long-term memory.

Von Glasersfeld (1988) pointed out that the first principle of *radical constructivism* can be traced back at least to Socrates: that knowledge is not passively received, but is actively built up by the cognizing student. According to Von Glasersfeld, the second principle is the revolutionary aspect of neoconstructivism: that the function of cognition is adaptive and serves to organize the student's experiential world, not of his or her discovery of ontological reality. The second principle asserts that knowledge need not, and in fact can not, be *true* in the sense that it matches ontological reality. The student's knowledge only has to be viable in the sense that it fits within the constraints of his or her world of experience, constraints that limit his or her possibilities of acting and thinking.

Among the consequences for education of the *neoconstructivist* perspective is the implication that the teacher must be interested in the student's *errors*, "... because it is these deviations from the teacher's expected path that throw light on how the students, at that point in their development, are organizing their experiential world" (Von Glasersfeld, 1988).

The work of Piaget is frequently referred to in the science education literature, and his fixed stages of cognitive development are perceived too often by science educators as representing a series of limitations. This interpretation of Piaget's model is not relevant to the present study. Pope and Gilbert (1983) reminded educators that Piaget had criticized the preoccupation with the notion of having to proceed from the simple to the complex in all domains of teaching. Piaget had noted that the logic of children deals at times with undifferentiated, global wholes, and at other times with isolated parts. Further, he suggested that some people may reach the level of formal operations in a specific area that they know well, without reaching formal levels in other areas. Pope and Gilbert argue that science educators should stress Piaget's epistemology which is, in their words, a "constructivist and relativistic view of knowledge in which the person's present construction of experiences forms the basis for the handling of new information and projections about future events."

Alternative conceptions in the physical sciences

The majority of the research into the alternative conceptions of students has been in areas of the physical sciences, primarily in topics of physics such as mechanics, electricity, and heat and temperature (Lawson, 1988). The general findings of these studies have been that the students' alternative conceptions significantly affected achievement and that conventional instruction fostered very little change in the naive conceptions.

Studies of several different alternative conceptions in physics (Clement, 1982; Ganiel & Idar, 1985; Hewson, 1985; Trowbridge & McDermott, 1980; Zietsman & Hewson, 1986) have shown that students' misconceptions can be investigated using situations of minimum complexity that help to isolate the sources of the errors. In at least two cases, the simplified situation has been supplied by computer simulation.

Ganiel and Idar (1985) used a questionnaire and a computer simulation to analyze students' preconceptions concerning the trajectory followed by a falling object dropped by a moving carrier. To facilitate diagnosis of misconceptions by the science teacher, the computer program tracked the user's performance in the simulation by recording for each fall of the object the relevant parameters at which it occurred.

Hewson and Zietsman (Hewson, 1985; Zietsman & Hewson, 1986) used a computer simulation of racing cars with high school and university physics students to diagnose, treat, and posttest the possession of the alternative conception wherein it is judged that, as one object overtakes and passes the other, the two objects have the same velocity when they are next to each other (i.e., the "position criterion").

Newtonian conceptions of force and motion: The second law of motion

In the Newtonian view of motion (an interpretation closer to that of present-day scientists than the Aristotelian view), the acceleration caused by one or more forces acting on an object is proportional in magnitude to the resultant of the forces, and parallel to it in direction, and is inversely proportional to the mass of the object. This is known as Newton's Second Law of Motion. The three alternative conceptions addressed in the present study are interpretations of the following situations: (a) two objects which fall to the earth from the same point, (b) an object upon which the resultant force is zero, and (c) objects which rise or fall. In the Newtonian view of situation (a), when two different objects fall toward the earth from the same point, each object experiences a downward gravitational force which is directly proportional to its mass ($F = mg$). Consequently, (neglecting air friction) each of the objects will fall with the same acceleration ($a = F/m = mg/m = g$), termed the acceleration due to gravity.

In situation (b), when the net force upon an object is zero, the Newtonian view is that the object's acceleration is therefore zero ($a = F/m = 0/m = 0$), and its velocity remains constant. This principle is termed Newton's First Law of motion, and is a special case of Newton's Second Law. In the Newtonian interpretation of situation (c), an object falls or rises because the resultant of the forces acting on it (including those due to collisions with air molecules) is downward or upward, respectively. The acceleration of the object is parallel to the resultant force in direction, directly proportional to the resultant, and inversely proportional to the mass of the object.

Aristotelian conceptions of force and motion

The following three alternative conceptions of force and motion, each more similar to Aristotelian explanations than to Newtonian explanations, are addressed in the present study. They each involve the inability to interpret the acceleration of an object as being elucidated by Newton's Second Law. (1) With no air resistance, the downward movement of a more massive object is faster than that of a less massive object. (2) If an object is moving and no unbalanced force is acting on it, the object will come to rest. (3) Light objects rise because they are made of material which naturally tends to move upward; heavy objects fall because they are made of material which naturally tends to move downward.

In the 4th century B.C., Aristotle set down in Book VIII of the Physica (McKeon, 1941, p. 366) his conclusions about the lightness and heaviness of objects. Concerning lightness, he maintained that ". . . air is actually light, and will at once realize its proper activity as such unless something prevents it. The activity of lightness consists in the light thing being in a certain situation, namely high up: when it is in the contrary position, it is being prevented from rising." Accounting for the motion of light objects upward and heavy objects downward, Aristotle held that ". . . the reason for it is that they [the objects] have a natural tendency respectively towards a certain position: and this constitutes the essence of lightness and heaviness, the former being determined by an upward, the latter by a downward, tendency."

Thus, Aristotle thought that objects were light or heavy by their *intrinsic nature*, and all substances had their *natural places* in the universe which they strove to reach with varying degrees of success (Jeans, 1951). In Aristotelian physics, heavy bodies fell and light bodies rose with speeds that depended on their lightness and heaviness. Aristotle asserted that the "downward movement . . . of any body endowed with weight is quicker in proportion to its size" (Halliday & Resnick, 1962). However, by the 16th century, Galileo Galilei (and earlier persons of science) had tested Aristotle's dictum by experiment and found it to be questionable.

The first alternative conception addressed in the present study, that *with no air resistance, the downward movement of a more massive object is faster than that of a less massive object*, is a notion similar to Aristotle's which is in line with many students' experience and which they carry into the physical science classroom. Through a series of experiments, Galileo found that although objects of different weight descend through a medium at different speeds, the difference between the speeds is less the more *tenuous* (less viscous) the medium. From these observations, Galileo extrapolated "beyond all possible experience" to an *ideal limiting-case*: in a vacuum all objects would fall the same (Garrison, 1986). Accordingly, the view today, in concert with Newton's Second Law, is that a gravitational force is exerted on each object directly proportional to its mass, and (neglecting air friction) each object falls toward the earth from the same point with the same acceleration--called the *acceleration due to gravity*.

Aristotle began Book VII of the Physica (McKeon, 1941, p. 340) with a pronouncement of the relation between force and motion: "Everything that is in motion must be moved by something." Thus, Aristotelian physics taught that all motion required a force to maintain it, so that an object on which no force acted must stand at rest (Jeans, 1951). Clement (1982) found that many college sophomores in an introductory course for beginners and science majors did not recognize friction as a force, and consequently believed that "continuing motion implies the presence of a continuing force in the same direction, as a necessary cause of motion."

Galileo contradicted the Aristotelian notion by extrapolating from experiment, concluding that a moving object acted upon by a zero resultant force will maintain its velocity until the resultant force becomes nonzero. The second alternative conception addressed in the present study, that *if an object is moving and no unbalanced force is acting on it, the object will come to rest*, is similar to the Aristotelian view that when an object has been moved by something else (which Aristotle termed the "movent"), ". . . it ceases to be in motion when its movent ceases to move it . . . ". To Aristotle, the "movent" was that which caused the motion of the object, but remained unmoved itself. The Newtonian view is that if the resultant force on an object is zero, then its acceleration is zero, and its velocity remains constant.

Aristotle maintained that objects fall or rise because they are striving to reach their *natural places*, places determined by the intrinsic nature of their substances. In chapter 4 of Book 8 of the Physica, he stated that "When these [light and heavy] things are in motion to positions the reverse of those they would properly occupy, their motion is violent: when they are in motion to their proper positions--the light thing up and the heavy thing down--their motion is natural . . . ". The third alternative conception addressed in the present study, that *light objects rise because they are made of material which naturally tends to move upward and heavy objects fall because they are made of material which naturally tends to move downward*, is similar to Aristotle's view. Students holding this conception do not recognize that an object's rising or falling depends on the forces due to gravity and to collisions with air molecules. The Newtonian view is that an object falls or rises because the resultant of the forces acting on it is downward or upward, respectively.

Changing students' conceptions

The instructional strategies which were incorporated into the computer simulations were consistent with the author's theory of instructionally eliciting conceptual change. In brief, the author proposes that the student who possesses an alternative conception can be instructionally facilitated in altering it by being made to recognize and discover a phenomenon which is anomalous to his or her conceptual framework and which epitomizes the relevant scientific concept. If the student is given adequate time to look repeatedly at the phenomenon, in effect *playing* with exemplars of the scientific concept by acting upon the objects and relationships of the phenomenon and then experiencing the consequences of that action, then the student will gradually adjust his or her conceptual categories in a complex manner until the phenomenon becomes anticipated. It is not necessary to be aware of all the intricacies of this complex conceptual adjustment in order to successfully elicit conceptual change.

In detail, the author's conceptual change theory involves the student's following three *stages of discovery*. In the student's actual experience of the conceptual change process, these stages are certainly not as neatly separated as their definitions imply. The stages of discovery may be further clarified by describing the *characteristics of discovery* and the *characteristics of the instructional situation* which presents the anomalous phenomenon to the student.

<u>Stages of the student's discovery</u>

1. Normal *seeing*

   Against the background of the student's framework of conceptions, he or she expects to see only certain phenomena. As a consequence, the student tends to perceive only that which is anticipated.

2. Awareness of anomaly

   If the student is allowed to act several times on that which is anomalous to his or her conceptual framework, and is allowed to experience the changes caused by his action, the student is likely to become aware that: a) something is wrong, or b) that he or she may relate the anomalous effect to something that has gone wrong before.

3. Conceptual adjustment

   The student's awareness of anomaly can start a period during which he or she will adjust his or her conceptual categories until that effect which initially appeared as *anomalous* will have become *anticipated.*

Characteristics of the student's discovery

1. It involves the student's trying

   Discovery requires responsibility on the student's part, not only to act upon the objects of the situation that involves the anomalous effect and to experience the circumstances, but also to consciously connect the action and the consequences.

2. It is complex

   Discovering something is not a single simple act; it is a complex event which involves gradually and simultaneously recognizing *that* the phenomenon exists and *what* the phenomenon is conceptually.

3. It takes time

   Discovery is a process and takes time.

4. It may involve student resistance

   The resulting change of conceptual categories is often accompanied by student resistance.

Characteristics of the instructional situation

1. It presents the scientific idealization of the anomalous phenomenon.
2. It exhibits cues which the student usually employs when making judgments in this area.
3. It confronts the student with an anomaly of such impact that the student is both informed that he or she is "wrong" (i.e., nonscientific) and is provided with clues necessary for reforming the conceptions.
4. It provides the student with enough controls over the situation that he or she can re-initiate the anomalous phenomenon several times.
5. It omits distracting variables which are unimportant for understanding the anomalous phenomenon.
6. The conflict deduced by the student from the anomalous phenomenon must be one that the student could confront in experiencing nature.
7. The deduced conflict must be one that, however vaguely perceived, has confronted the student before.

The two computer simulations were designed to facilitate the student's passage through the *stages of discovery* in the following ways. Each simulation focussed the student's attention on a phenomenon, a scientific ideal case, which was in contradiction to one or more of the alternative conceptions which had been diagnosed by the Selection Test. The student reran the first simulation ten times and the second simulation five times, so that the student had time: a) to become aware that the highlighted phenomenon was anomalous to his or her conceptual framework, and b) to adjust his or her conceptual categories until the student came to expect the phenomenon each time. Each simulation exhibited cues by which the student usually judges the motion of objects. Each simulation was designed to abate many feelings of resistance to discovery that the student might feel, by employing various principles of human-computer interactivity (Weller, 1988) in order to: a) make the student feel in control of the simulation, and b) provide him enjoyment and satisfaction in running the simulation.

The author's theory of instructionally eliciting conceptual change has been drawn principally from five sources: 1) Thomas Kuhn's theoretical views a) of the role of anomaly in the discovery by a scientific community of a new and unsuspected phenomenon (Kuhn, 1970), and b) on the function of *thought experiments* in science (Kuhn, 1977); 2) John Dewey's (1916) views on the relation of experience to thinking; 3) the model of Posner, Strike, Hewson and Gertzog (1982) for the facilitation of conceptual change in science; 4) the criticism of the model of Posner et al. by Garrison and Bentley (1990) for its assumption that a student's learning is a *rational* activity, ignoring *pre-rational* considerations in learning; and 5) the author's own observations which have been collected during twelve years of teaching various physical science courses in Grades 8-12.

The author is indebted to Posner et al. (1982) for their argument that the patterns of conceptual change in the learning of a science student are analogous to what current philosophers of science have described as the patterns of conceptual change in scientific communities during *scientific revolutions*. Posner et al. drew upon the philosophical works of Thomas Kuhn, Imre Lakatos, and Stephen Toulmin. The author differed with the commitment of Posner et al. to learning being a *rational* activity, where the student comes "... to comprehend and accept ideas because they are seen as intelligible and rational" and the student "... must make judgments on the basis of available evidence." The author's teaching experience had led him to believe that much of the learning of 8th-grade science students is often not *rational* in the scientist's sense, because they have not learned enough about how the scientist reasons and what the scientist considers as sound evidence. However, building upon the idea of Posner et al. that the learning of a student could be viewed as a process of conceptual change which is analogous to the conceptual change of scientific communities, the author has drawn strongly upon Kuhn's ideas concerning the role of anomaly in a scientific community's discovery of a new and unsuspected phenomenon.

The author found the three steps in the process of a scientific community's discovery that Kuhn (1970) describes, as analogous to the *stages of discovery* that the instructor wishes to elicit in the process whereby the student becomes aware of, and alters, an alternative conception. For Kuhn, these stages are:

1. Normal science

   "Against a background provided by expectation," the scientist tends to perceive only that which is "anticipated and usual."

2. Awareness of anomaly

   If the scientist is continually exposed to that which is anomalous to his or her background, he "does become aware that something is wrong, or does relate the effect to something that has gone wrong before."

3. Conceptual adjustment

   "That awareness of anomaly opens a period in which [the scientist's] conceptual categories are adjusted until the initially anomalous has become the anticipated."

For the *characteristics of the student's discovery*, the author drew upon: a) Kuhn's (1970, p. 64) description of the characteristics common to all discoveries in science from which new phenomena emerge, and b) John Dewey's (1916, p. 139) description of experience as an active-passive affair, in which "Experience as trying involves change, but change is meaningless transition unless it is consciously connected with the return wave of consequences which flow from it."

For the *characteristics of the instructional situation*, the author drew first upon Garrison's (1986) description of the substitution by natural science of a mathematical world of idealities for the everyday world of experience. This description of science as an extrapolation from the experiential world explained why science students have "... difficulty in learning idealized worlds such as science, worlds that represent a discontinuous break with ordinary everyday practical experience" (Garrison & Bentley, 1990). Unfortunately, many science teachers do not realize fully that "Many, if not most, theories deal with ideal cases. Scientists neither believe such theories nor do they accept them as true" (Laudan, 1981). In order to teach the student the concepts of the idealized world of science, the instructional simulation must present the idealization of the phenomenon of interest. The student's gradual adjustment of conceptual categories until he or she anticipates the idealized phenomenon is consistent with the neoconstructivist view of learning as an ongoing construction of meaning.

For most of the remainder of the *characteristics of the instructional situation*, the author drew upon Kuhn's (1970) description of the conditions of verisimilitude which must apply to a *thought experiment* for it to lead successfully to new knowledge or to new understanding of nature. Kuhn pointed out that thought experiments have several times played important roles in the development of physical science. Well-known examples are Einstein's train struck by lightning at both ends and the Bohr-Heisenberg microscope. The author maintained that the conditions of a successful *thought experiment* for a scientist (discussed on page 27) are analogous to the conditions of the instructional situation which successfully elicits conceptual change for a science student.

Although the author did not draw explicitly from the conceptual change model of Posner et al. (1982), several ideas were drawn implicitly from it. However, the author always kept in mind the criticism of this model by Garrison and Bentley (1990) for its assumption that learning is strictly a *rational* activity. This criticism was similar to the author's own concern that an 8th-grader's learning of science is not solely *rational*. The model of Posner et al. holds that if learning is envisioned as a change in a student's conception, then learning involves an interaction between existing conceptions and new conceptions, with the outcome being dependent on the nature of the interaction (Hewson, 1985). If the new conceptions can be reconciled by the student, then learning will proceed without difficulty. However, if they cannot, then learning will require that the student's existing conceptions be restructured, or even exchanged for, the new conceptions.

Posner et al. (1982) have proposed that there are four important conditions which must be fulfilled for most instances of radical conceptual change (i.e., the person's replacement or reorganization of his or her central concepts) to occur:

(1) There must be dissatisfaction with existing conceptions.

(2) A new conception must be intelligible (i.e., the student must be able to construct a coherent representation of it, and it must be internally consistent).

(3) A new conception must appear initially plausible (i.e., provide the capacity to solve the problems which its predecessor conception has generated, and it must be reconcilable as true with other conceptions which the student holds).

(4) A new conception should suggest the possibility of a fruitful research program.

To foster conceptual change according to the above model, Hewson (1985) has proposed that after diagnosing the alternative conception, a teacher should: (a) address the naive conception with the explicit intention of creating dissatisfaction with it; and

(b) explain the new ideas in order to make the new conception intelligible and plausible to the student. In the present study, it is hypothesized that the computer program's two simulations will fulfill these two teacher roles, at least to the extent that the students will be facilitated in altering their naive conceptions.

Garrison and Bentley (1990) maintain that although the model of Posner et al. is satisfactory for *conceptual* development and learning, the theory is incomplete because it assumes that a complete account of science learning can be given entirely in terms of concepts and their relations. They find that the approach of Posner et al. ignores other aspects of conceptual development such as interest, selective attention, systematic doubt, and the process of abstraction. Garrison and Bentley use the term "precognitive" to describe learning that takes place before the individual's formation of complete concepts and categories and criticize the assumption of Posner et al. that learning is a purely *rational* activity.

The premise of rationality does not recognize that the idealized system of science represents for the student another world, with standards of what constitutes valid reasoning and sound evidence which are entirely different from the world of everyday practice. Until the student learns these new canons of rationality, he or she must utilize the *pre-rational* to achieve an *original* learning of science. Garrison and Bentley hold that this original learning of science must be carried out in a fashion very similar to learning a new language, that is, by *playing the game of science*. This is done by encountering examples of situations that scientists have already learned to view as being alike, and as being different from other types of situations (e.g., ideal gas laws, free fall in a vacuum, and motion along frictionless surfaces).

To the author, the criticism by Garrison and Bentley of the conceptual change model of Posner et al. was equivalent to postulating that a beginning student's learning of a science concept does not occur by a *quantum jump* from a state of science ignorance to a state of conceptual cognizance by means of a rational absorption and assessment of the conflict between a concept drawn from everyday experience and a science concept. Rather, the student must build up a supportive web of familiarity with exemplars and nonexemplars of science thinking which will allow him or her to surmount the barrier of abstraction, judgment, and emotional acceptance between the naive concept and the science concept.

The microcomputer simulations in the present study have been designed to foster conceptual change by allowing the student to *play the game of science*, encountering exemplars of the idealized scientific view of (a) free fall in a vacuum and (b) motion with all the forces shown. In this way, the student can utilize both *rational* and *nonrational* processes of learning.

Instructional microcomputer simulations

Simulation is the "process of interacting with a model that represents reality" (Lunetta & Hofstein, 1981). According to Gagne' (1962), a simulation: (a) represents a real situation in which operations are carried out, (b) provides the user with certain controls over the problem or situation, (c) omits certain distracting variables which are irrelevant or unimportant for the particular instructional goals.

The two aspects of the microcomputer which enabled Zietsman and Hewson (1986) to use it in their study of students' use of the "position criterion" to judge the velocities of two objects were: (1) the capability, during diagnosis, of simulating real-world experiences which are difficult to replicate, are too complicated, and/or happen too rapidly to be observed easily; and (2) the capability of branching from diagnosis to remedial instruction which is specific to the diagnosed alternative conception.

There have not been many rigorous studies to date of the validity and effectiveness of computer simulations in physics teaching. Twelker (1968) has suggested that the degree to which a simulation corresponds with the real-world situation it is designed to simulate may be crucial to learning. He felt that if there is a *credibility gap* between instruction and the operational world, then the learner may be at a disadvantage when it comes to performing in and/or understanding the real world. This view does not take into account the fact that the world of science is actually an abstraction from the world of practical experience.

In an alternate view, Kuhn (1977) has proposed conditions necessary for the effectiveness of *thought experiments* in eliciting conceptual change, conditions which do not require strict physical verisimilitude. A thought experiment is one that is imagined by the scientist, but not actually carried out. It may involve a situation that has not been examined in a laboratory, or even a situation that could not possibly occur in nature (Kuhn, 1977). This writer maintains that Kuhn's conditions can be applied directly to the design of simulations to successfully induce conceptual change. Kuhn put forth this proposal as the conclusion of speculation about the crucial role that thought experiments have had in the development of physical science, despite their having often dealt with situations that had not been subjected to laboratory examination, could not have possibly been examined fully in a physical fashion, and/or need not even have occurred in nature.

Arguing that from thought experiments most people learn about both their own conceptions and the world, Kuhn held that a thought experiment must be capable of confronting the thinker with a paradox of such impact concerning the person's incorrect conceptions, "transforming felt anomaly to concrete contradiction," that the person is both informed that he or she is wrong and provided with clues necessary for *reforming* the conceptions.

Concerning the conditions necessary for this impact, he concluded first that although the situation imagined in the thought experiment need not even be potentially realizable in nature, it must exhibit the *cues* which the thinker usually employs when making judgments in this area. Secondly, the conflict deduced from the imagined situation must not only be one that nature itself could present, but also must be one that, however vaguely perceived, has confronted the thinker before.

Microcomputer program for diagnosis and remediation

In the present study, a microcomputer program was used (a) to diagnose physical science students' alternative conceptions concerning falling objects, rising objects, and the inertia of moving objects; and (b) to facilitate the alteration of these conceptions by placing the student in an environment where he or she could *play the game of science* in simulated situations where the student's naive conception was at conflict with a displayed phenomenon, and where he or she could experiment with exemplars of the *more scientific* concept until the conflicting phenomenon became the anticipated phenomenon. The diagnosis or posttesting mode was very different from the remediation mode.

Hewson and Zietsman (Hewson, 1985; Zietsman & Hewson, 1986), have employed one computer simulation mode to treat, as well as to diagnose and posttest the subjects, that is, by testing the subjects in the *world* of the simulation rather than in the classroom world. They have avoided the possible existence of a credibility gap between the science world (of the simulation) and the classroom world by testing the credibility of the computer simulation for the students separately against the apparatus that it simulated.

The present study took an alternative approach, utilizing computer simulation only for the treatment. The students were diagnosed and posttested by the computer program via text and graphics, modes which are more similar to the typical classroom evaluation situation than is computer simulation. The author has written a Pascal program for the IBM PC/XT microcomputer which was designed to diagnose, via graphics and questions, the above three Aristotelian alternative conceptions of high school physical science students and to facilitate the remediation of the alternative conceptions by means of two computer simulations.

Chapter 3

METHODOLOGY

Strategy

The recent literature on alternative conceptions in science (Ganiel & Idar, 1985; Hewson, 1985; Zietsman & Hewson, 1986) suggested the hypotheses that: (a) a micro-computer program might be used to diagnose physical science students' alternative conceptions concerning falling objects, rising objects, and the inertia of moving objects; and (b) the program could then facilitate the alteration of these conceptions by placing the student in an environment where he or she could *play the game of science* in order to become familiar with exemplars of the appropriate scientific concepts.

The author has written a 4300-line Pascal program for the IBM PC/XT microcomputer (with EGA monitor and at least 384 K RAM memory) which is designed to diagnose, via graphics and questions, three Aristotelian alternative conceptions of 8th-grade physical-science students, to facilitate the students' alteration of the conceptions by means of two computer simulations, and to posttest for changes in the conceptions. The simulations are termed the Objects Falling simulation and the Cube Moving simulation. The alternative conceptions addressed are:

1) *Quickness of fall depends on mass* conception

   With no air resistance, the downward movement of a more massive object is faster than that of a less massive object.

2) *Unbalanced force* conception

   If an object is moving and no unbalanced force is acting on it, the object will come to rest.

3) *Direction of vertical movement depends on type of material* conception

a) Light objects rise because they are made of material which naturally tends to move upward; b) heavy objects fall because they are made of material which naturally tends to move downward.

To lay a foundation for the computer diagnosis and intervention study, it was first necessary to investigate, via structured interviews, whether a sample of 8th-grade physical science students who had completed the study of the corresponding more-scientific conceptions in a force-and-motion unit several weeks earlier (the *completed* students) showed evidence that they possessed one or more of the above three alternative conceptions. Although there was evidence in the literature of science students' possession of alternative conceptions # 1 and # 2, the author felt that without the empirical foundation of the structured interviews, there would have been little justification for continuing the study. The structured interviews were used, also, to determine whether the computer diagnostic test did, in fact, address these three alternative conceptions (i.e., to determine the content validity of the test).

The structured interviews indicated that several students possessed alternative conceptions # 1, # 2, and # 3a. Following the satisfactory results of this ground work, the computer diagnosis portion of the study was used simultaneously for two purposes. The first purpose was to determine whether 8th-grade students who had completed the study of force and motion several months earlier (*completed* students) actually exhibited patterns of nonscientific answers ("errors") which differed from the "error patterns" of students who were currently studying force and motion (*in-process* students). Since *in-process* students were expected to possess more naive conceptions before starting the unit on force and motion than when they had finished it, *in-process* students were expected to exhibit a higher frequency of "error" answers on the diagnostic test than *completed* students. This was investigated by administering the computer diagnostic test to both groups of students.

The second purpose of the computer diagnosis was to employ the "errors" of the *completed* students to determine their possession of the above three alternative conceptions, conceptions that are contrary to the concepts of force and motion that are taught in 8th-grade physical science. A *completed* student's possession of one or more of these naive conceptions was diagnosed by means of on-screen multiple choice questions, with accompanying graphics to facilitate the subject's visualization of each question situation. The multiple choice-graphics format for testing of subjects is similar to a testing format commonly employed in the classroom, a format which has also been utilized for diagnosis of alternative conceptions of force, motion, and other topics by several researchers (e.g., Glasson, Teates, & Roychaudhury, 1989; Halloun & Hestenes, 1985; Osborne & Freyberg, 1985, p. 45; Posner & Strike, 1989).

Following the selection by the diagnostic test of those *completed* students who possessed one or more of these alternative conceptions, this study investigated whether the students who worked through the two remedial simulations would change their conceptions concerning falling objects, rising objects, and/or the inertia of moving objects. Evidence of change was determined by administering the computer posttest both to *completed* students who had worked the simulations and to *completed* students who had not.

Finally, one and one-half months after the initial use of the computer diagnosis-and-remediation system by the *completed* students, the students' retention of simulation-elicited changes in their alternative conceptions was assessed. The robustness of any changes in the alternative conceptions of the students who had worked through the computer simulations was determined by re-administering the posttest on the computer or pencil-and-paper to a sample of those students. At this time, brief interviews were also employed to check on the students' understanding of the situations that had been represented by the computer simulations.

Computer simulations

The two simulations were idealized representations of situations which the student could have experienced in nature, representations intended to present cues presumed to be important to the process of making judgments about force and motion. The simulations addressed a student's alternative conception by presenting situations that conflicted with it, with the intention of eliciting the student's dissatisfaction with the naive conception. The simulations fostered conceptual change by enabling the student to *play the game of science*, experimenting with exemplars of the *more scientifically acceptable* concept until the conflicting phenomenon became the anticipated phenomenon. The simulations were fashioned so that the conflict between conceptions which the student deduced from each representation was one that could have actually occurred in the person's experience of the world, and with which the person had very likely been confronted before (even if quite vaguely perceived). The student ran the first simulation ten times, and the second simulation five times, each time with different parameters.

For the final version of the Objects Falling simulation, the student chose the materials from which two objects were composed, and the height on a tower from which those objects fell. The student also chose the mass of each object, unless the object was a steam droplet or a dust particle (whose masses were merely stated as "tiny"). The simulation runs were alternately in an environment of *air resistance* or *no air resistance*. In the cases when the objects fell from the tower to the ground, the right half of the screen showed at different times: a) no supplemental information, b) two downward arrows representing analagously the current speed of fall of the objects, c) the increasing times of fall, speeds, and distances fallen of the objects. In the cases when the objects did not fall (i.e., in the case of the steam droplet or the dust particle in an environment of no air resistance), then the supplemental information was not provided.

When the objects fell with no air resistance, they moved simultaneously at opposite sides of a tower and struck the ground at the same time. Both the parallel fall of the objects past tower storeys and the simultaneous impact with the ground presented cues which a person customarily employs when making judgments about falling objects.

The Objects Falling simulation was designed to provide, in the case of no air resistance, a situation in direct conflict with the beliefs of the student who had a *quickness of fall depends on mass* alternative conception (i.e., who believed that the object with more mass will strike the ground first). The conflict was one which could occur in nature when objects much denser than air are dropped within a few meters near the earth, and one that the student had quite likely encountered before (however vaguely perceived). The simulated fall of the two objects, as well as the supplemental information, provided clues to allow the student to work toward altering his or her conception.

The Objects Falling simulation was also designed to provide, via the contrast of the air resistance and no air resistance environments, situations in direct conflict with the beliefs of the student who had a *direction of vertical movement depends on type of material* conception (i.e., who believed that light objects rise because they are made of material which naturally tends to move upward, and heavy objects fall because they are made of material which naturally tends to move downward).

For the final version of the Cube Moving simulation, the student chose the mass and initial horizontal velocity of a cube. For each simulation run, the computer system chose four new forces which were exerted on the cube throughout its motion (an upward force, downward force, force from the left, and force from the right). While the cube moved across the screen, the forces upon the cube were represented by arrows with lengths proportional to their magnitudes. During the motion, an arrow in the upper left portion of screen represented the current velocity of the cube. The magnitude of the velocity was also printed alongside the arrow.

Before the Cube Moving simulation started, two diagrams at the bottom of the screen informed the student whether the horizontal forces on the cube were balanced, and/or whether the vertical forces were balanced. The motion of the cube relative to the screen borders, and to the cube's initial starting point, presented cues which a person typically uses when making judgments about moving objects.

Whenever the four forces were balanced in the Cube Moving simulation (i.e., when the resultant force was zero), the cube did not come to rest. Instead, it continued to move with its initial velocity. This situation was in direct conflict with the beliefs of the student who had an *unbalanced force* conception (i.e., who believed that a moving object on which the forces are balanced will come to rest). The conflict was one which could occur in nature when massive objects moved across low-friction surfaces (such as ice), or when objects moved at large distances from the earth (which the student might have observed in films of astronauts on board a satellite). It was also a conflict that the student had probably been confronted with before. As in the Objects Falling simulation, the motion of the cube, as well as the supplemental information, provided clues to allow the student to work toward altering his or her conception.

This diagnosis-and-remediation system was designed so that a student could complete the program on a microcomputer in about 25 minutes during class, study hall, or even at home. The student's answers to the program's diagnostic and posttest questions, as well as the number of times he or she repeated each simulation were recorded on the diskette for the teacher to examine later. With a five-minute perusal of the student's answers, the teacher would be presented with an indication of of the student's possession of one or more of the above three alternative conceptions, as well as evidence of any conceptual changes fostered by the program.

If successful in diagnosis and remediation, this system could serve as a prototype for similar microcomputer programs which would deal with many of the well-characterized alternative conceptions known to occur in the learning of secondary school science. Each program would require only the availability of a microcomputer, approximately 25 minutes of each student's time, and about five minutes of teacher examination time per student.

Pilot studies

Two pilot studies were conducted with the computer diagnosis-and-remediation system, in order to ascertain: a) the appropriateness for 8th-graders of the diagnosis language and the simulations, and b) the feasibility of inducing the alteration of the above three alternative conceptions of 8th-graders with such a system.

In the first pilot study, fifteen 8th-grade physical science students at a suburban private K-12 school in a medium-sized city were administered the diagnostic portion of the microcomputer program. The students had studied force and motion five months earlier in their science class. The five questions in the Selection Test were similar to questions 1, 2, 3, 4, and 8 in the final eight-question version of the test (see Figures 1-6). The Selection Test selected twelve of the students for possession of one or more of the above three alternative conceptions of force and motion. Six of the selected students were assigned randomly to the experimental group which worked through the two remediation simulations (see Appendix B); six were assigned randomly to the control group which did not do the simulations.

Following the simulations, each student in the treatment group was administered the posttest portion of the computer program. Each student in the control group was given the posttest after doing the diagnostic test, following a time interval equal to the average time required by an experimental-group student on the simulations. The mean score of the experimental group on the computer posttest was significantly superior to that of the control group, as determined by a *Student's t* test for independent samples ($t = 3.545$, $p < 0.05$).

Two types of changes were made to the computer diagnosis-and-remediation system before the second pilot study was conducted. First, while working the Cube Moving simulation, most of the experimental group students did not balance the forces on the cube. As a result, they could not possibly observe that a moving object on which all the forces were balanced would continue to move with the same speed and direction. Therefore, a statement hinting that the student should balance the forces was added to the Cube Moving simulation before the second pilot study was conducted. Second, before the second pilot study was conducted, the two experts who validated the language and content of the Selection Test questions recommended several changes in the vocabulary, in order to clarify the questions and to reduce their sophistication to the 8th-grade level. These changes were implemented before the second pilot study.

No test was conducted in either pilot study of the robustness over time of any conceptual changes induced by the computer simulations.

In the second pilot study, 16 eighth-grade physical science students at an urban, public, middle school in a large town were administered the diagnostic portion of the computer program. The students had just finished studying force and motion in their physical science classes. Seven of the nine questions in the Selection Test used in the second pilot study were similar to questions # 1-4 and 6-8 in the final eight-question version of the test (see Figures 1-6). Eight students, randomly assigned to the experimental group, answered the Selection Test questions and then worked their way through the two simulations. The eight other students, randomly assigned to the control group, answered the Selection Test questions but did not do the simulations. They filled out attitude questionnaires concerning their opinions of the Selection Test, while the experimental group did the simulations. Then, all 16 students answered the PostTest questions. Following the administration of the posttest, four of the students from the treatment group were interviewed, each for 15 minutes. See Appendix A for a sample transcript of one of the interviews.

Although the experimental group students answered a fractionally higher average number of questions on the computer posttest in a scientific manner than did the control group students, it was not significantly superior as shown by a *Student's t* test.

The purpose of the four interviews after the posttest was to ascertain whether: 1) 8th-grade physical science students actually possess one or more of alternative conceptions 1-3, 2) the language employed in the Selection Test was appropriate for 8th-graders, and 3) the situations represented by the two simulations were recognized and understood by the students.

Each student was shown several of the pictures for the questions from the Selection Test on paper. The interviewer asked the students to indicate the answer they had put for each question and to explain why they had put it. These pilot-study interviews were not as *clean* as the structured interviews which were performed later (described in the next section). In the pilot study interviews, the students had seen the possible answers for each question on the computer screen, and might have selected ideas from these answers for some of their explanations during the interviews. In the later structured interviews (next section), the students had not seen the pictures and questions before.

In the the pilot-study interviews, the statements of several of the students indicated that they possessed one or more of the alternative conceptions # 1-3a. Martin possessed a *direction of vertical movement depends on type of material* alternative conception. When shown the Steam Rising question (Figure ?), he said that the "fumes" rise "... because they belong in the air."

Two of the students possessed *quickness of fall depends on mass* alternative conceptions. When asked which object would strike the ground first when a light object and a heavy object are dropped at the same time from the same height, and there is no air resistance, Martin said "The heavy object." When asked which of the objects would speed up more quickly, he replied "The heavy object." Les possessed a different variation of an *unbalanced force* alternative conception. He stated that the pencil would strike the ground before the brick, and that the pencil would be moving faster when it struck the ground than would the brick.

Two students possessed *unbalanced force* alternative conceptions. The interviewer described the following situation to Martin: an object is already moving, and all the forces on it cancel each other. When Martin was then asked what would happen to the motion of the object, he replied that "It will stop." When Tom was asked what would happen to a moving object on which all the incident forces cancelled each other, he replied that it would "... go faster."

In order to determine whether the situations represented by the two simulations were recognized and understood by the students, each student was shown pictures of one or both of the simulations on paper. The three students who were shown a picture of the Objects Falling simulation each grasped the represented situation and the point of the simulation fairly well. Martin recognized the situation, and grasped its purpose up to a point. When asked to state the point of the simulation, he said "That all the things are gonna fall at the same speed ... and land at the same time." However, it was apparent that Martin did not understand that the objects accelerated as they fell. Barbara understood the situation represented, perhaps even better than did Martin. She said that "... it helped me understand that the weight didn't matter and all that, 'cause they [the two objects] fell equally no matter what I put." Les understood that in the simulation the objects "... went down at the same time ... both of 'em."

However, none of the four students seemed to have understood the purpose of the Cube Moving simulation. Martin stated that he had ignored the on-screen hint that he should try making his force selections *balance* so that they would cancel each other. Tom said that he had not chosen his forces to balance, either. He said that he did not understand the point of the simulation. When asked about the point of the simulation, Barbara stated that "I have no idea what that did." Les said that "I didn't understand that one," but added that he had only worked through the Cube Moving simulation one time.

It was decided by the researcher that the two simulations were not having enough instructional impact upon the experimental students for two reasons: 1) the simulations were not providing the students with enough content which was relevant to changing their alternative conceptions, and 2) the students (who were given the option of repeating each simulation as many times up to 10 as they wished) were observed to repeat each one only once or twice. Further, it was deemed by the two validation experts that: a) the vocabulary of several of the Selection Test questions was too difficult for 8th-grade science students, and b) one of the Selection Test questions was of a higher level of difficulty than is typically covered in an 8th-grade physical science class. Following the second pilot study, the Selection Test vocabulary was made more appropriate for 8th-grade science students and the difficult question was eliminated from the Selection Test.

Following the two pilot studies, in order to increase the instructional impact of the two simulations upon the students, it was decided that two measures would be taken. First, all experimental group students would henceforth have to run the Objects Dropping simulation 10 times and the Cube Moving simulation 5 times. Second, both simulations would be redone in order to supply more information to the student.

In the Objects Dropping simulation, an option was added wherein the current velocity of each falling object was represented in the table by a downward arrow. The length of the arrow represented the magnitude of the object's current velocity. Also, this simulation was altered so that the objects fell in one-half of the simulation runs in an environment of no air friction. In the other half of the runs, they fell in an environment with air friction.

The Cube Moving simulation was altered so that during the motion of the cube across the screen, an arrow was shown which represented the current velocity of the cube. The direction of the arrow represented the current direction of the velocity; the length of the arrow represented the magnitude of the velocity. The magnitude of the current velocity was also shown alongside the arrow. Also, two diagrams were added (at opposite corners of the bottom of the screen) which informed the student whether the horizontal forces and/or the vertical forces upon the cube were balanced.

Computer simulations: Students' understanding of the situations represented

Interviews conducted with a sample of seven 8th-graders after they had taken the Retention Test provided information on the students' understanding of the two computer simulations in the diagnosis-and-remediation system. With respect to the Objects Falling simulation, the statements of all six students who were asked about this simulation indicated that the cues it exhibited clearly represented the situation of two falling objects.

When referring to the fall of an object, Connie explained that "It looked like it was falling, 'cause it was going straight down." She indicated that the presence of the tower provided clues for judging the fall of an object, because "You could remember how far it fell, with the building--from where it fell. I mean, if it was just a blank screen, you could never remember how far it fell." She also commented on the provision of cues by the tower which aided comparison of the falls of the two objects. "You can--um--compare the two objects easier, I think with the building there."

Mike said that the picture on the Objects Falling screen contributed to the representation of a falling object by means of "The building, the door, the windows, the ground ... type of things." Mike was aided in comparing the falls of the two objects by the values displayed in the table on the screen. "These letters over here represent the time of the falling, distance of the falling, and downward speed and they're all the same." He was also aided in his comparison by the impacts of the objects upon the ground in the simulation. "Well, they both hit about the same time."

Some students indicated that the cues provided by the presence of the tower were not necessary. Mark said that he knew the objects were falling because "They just went down." Betty stated that "We saw 'em going down, instead of up."

Three students were asked about the Cube Moving simulation. This simulation represented more generic force and motion for the students than did the more situation-specific Objects Falling simulation. Two students indicated that they were not as confident that they understood the Cube Moving simulation as well as they understood the Objects Falling simulation. Rita said that "I really didn't understand this one like I did the other one." Before running the Cube Moving simulation, Mike said that "I don't know what's gonna happen." However, as he started running this simulation, Mike did predict correctly what the motion of the cube would be.

Russell's comments indicated that he understood the Cube Moving simulation very well. He stated that this simulation didn't need more cues than it had. "No, 'cause you can see it move." However, he did not notice that the simulation did mark the initial point of the cube's motion. He suggested that "You might want to put a starting point to show that it moves."

Sample

The writer implemented a series of interventions with a representative sample of students drawn from 8th-grade physical science classes at three schools, with 29, 31, and 36 students, respectively. The first school was a suburban private school for grades K-12; the second and third each were high schools which drew students from large rural areas containing several large towns. The sixty students from the first and second schools had studied force and motion in their physical science classes 2 and 6 months earlier, respectively. In this report, they will often be referred to as the *completed* students. The *completed* students utilized this microcomputer program for the diagnosis and remediation of the above three Aristotelian alternative conceptions.

The thirty-six students from the third school were currently studying force and motion in their physical science classes. In this report, they will often be referred to as the *in-process* students. The *in-process* students utilized the program in the same manner as the group of *completed* students, for the purpose of comparison of the patterns of nonscientific answers ("errors") of the *in-process* and of the *completed* students.

Instrumentation

Two experts assessed the content validity of the questions used in the computer Selection Test (Figures 1-6). The same questions were also used in a) the computer posttest, b) the structured interviews, and c) the Retention Test (which was taken 1.5 months later either via computer or pencil-and-paper). These assessors were science educators who were experts in the force-and-motion content of physical science and in the teaching of physical science topics, and who had conducted research themselves on alternative conceptions typically occurring in the learning of physical science.

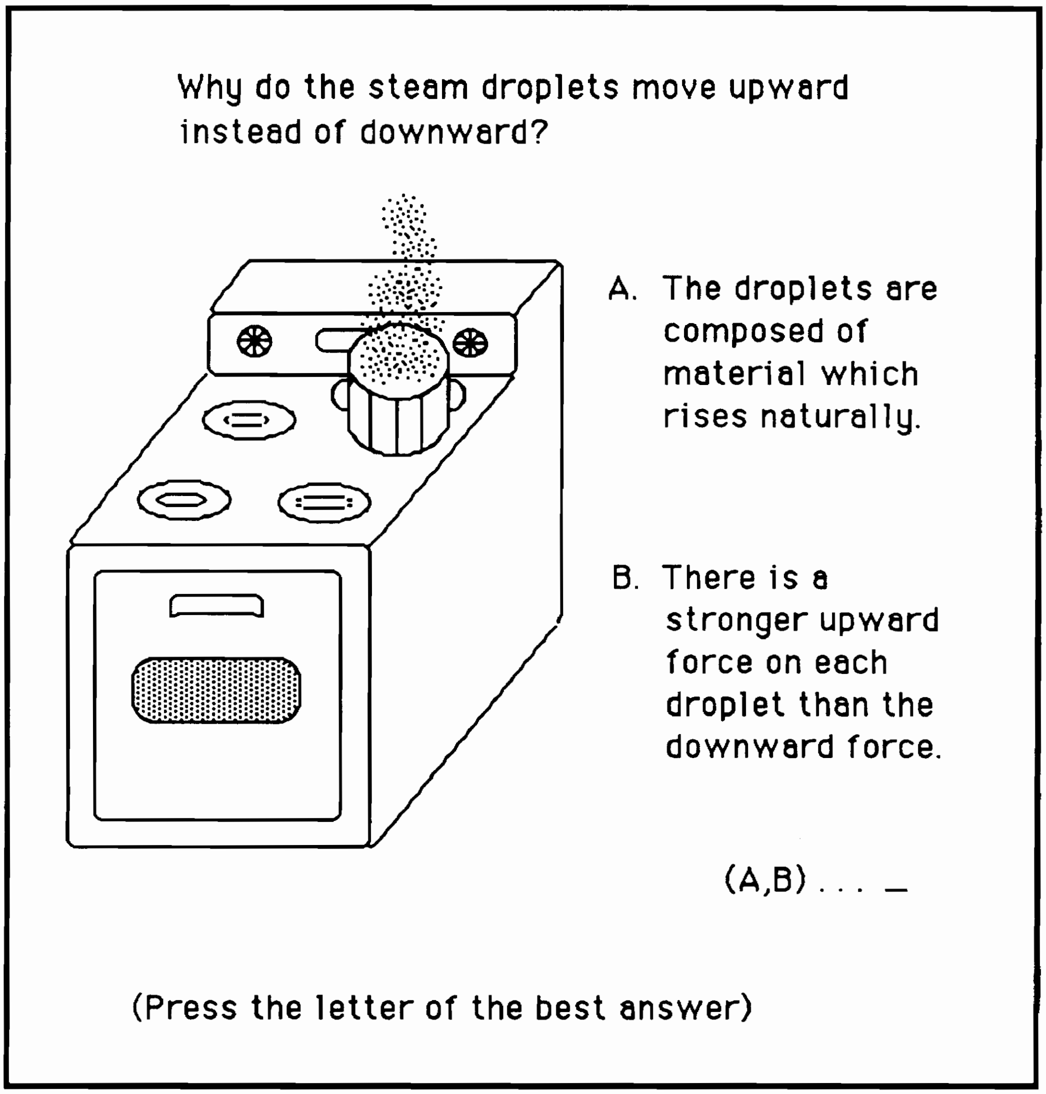


Figure 1. The Vapor Rising question on the final version of the computer Selection Test.

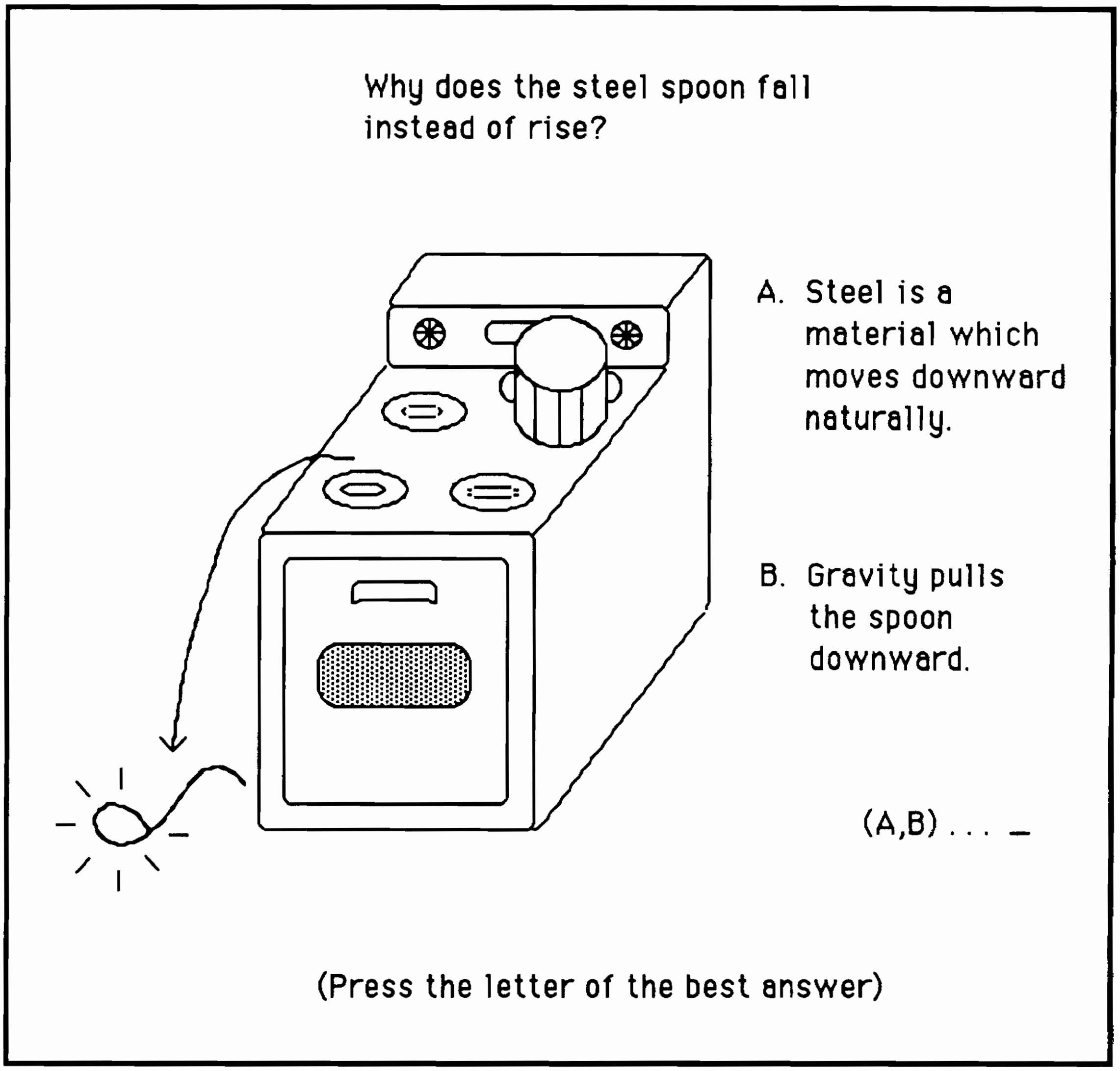
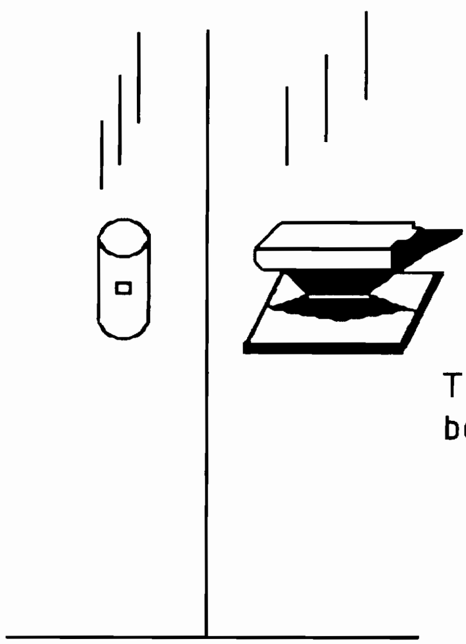


Figure 2. The Spoon Falling question on the final version of the computer Selection Test.

An iron anvil and an aluminum can
are held the same height above the floor,
and dropped at the same time.



With no air resistance,
which object will gain
speed faster?

A. Anvil
B. Aluminum can
C. They gain speed equally

(A,B,C) . . . _

The anvil falls, rather than rises,
because

A. Iron is a material
which moves downward
naturally.

B. Its weight pulls
it downward.

(A,B) . . . _

(Press the letter of the best answer)

Figure 3. The Anvil-Can Falling and Why Anvil Falls questions on the final version of the computer Selection Test.

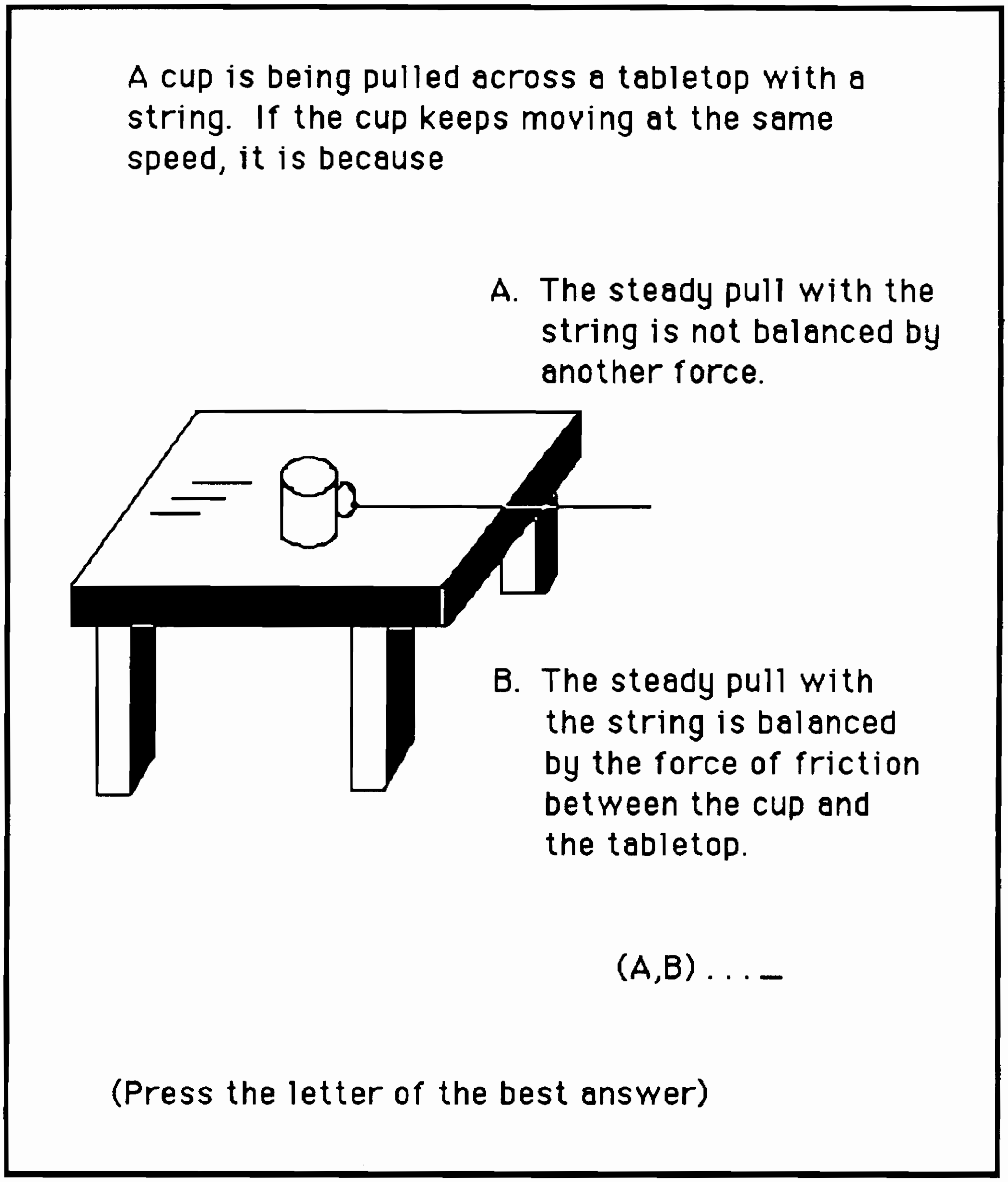


Figure 4. The Cup Sliding question on the final version of the computer Selection Test.

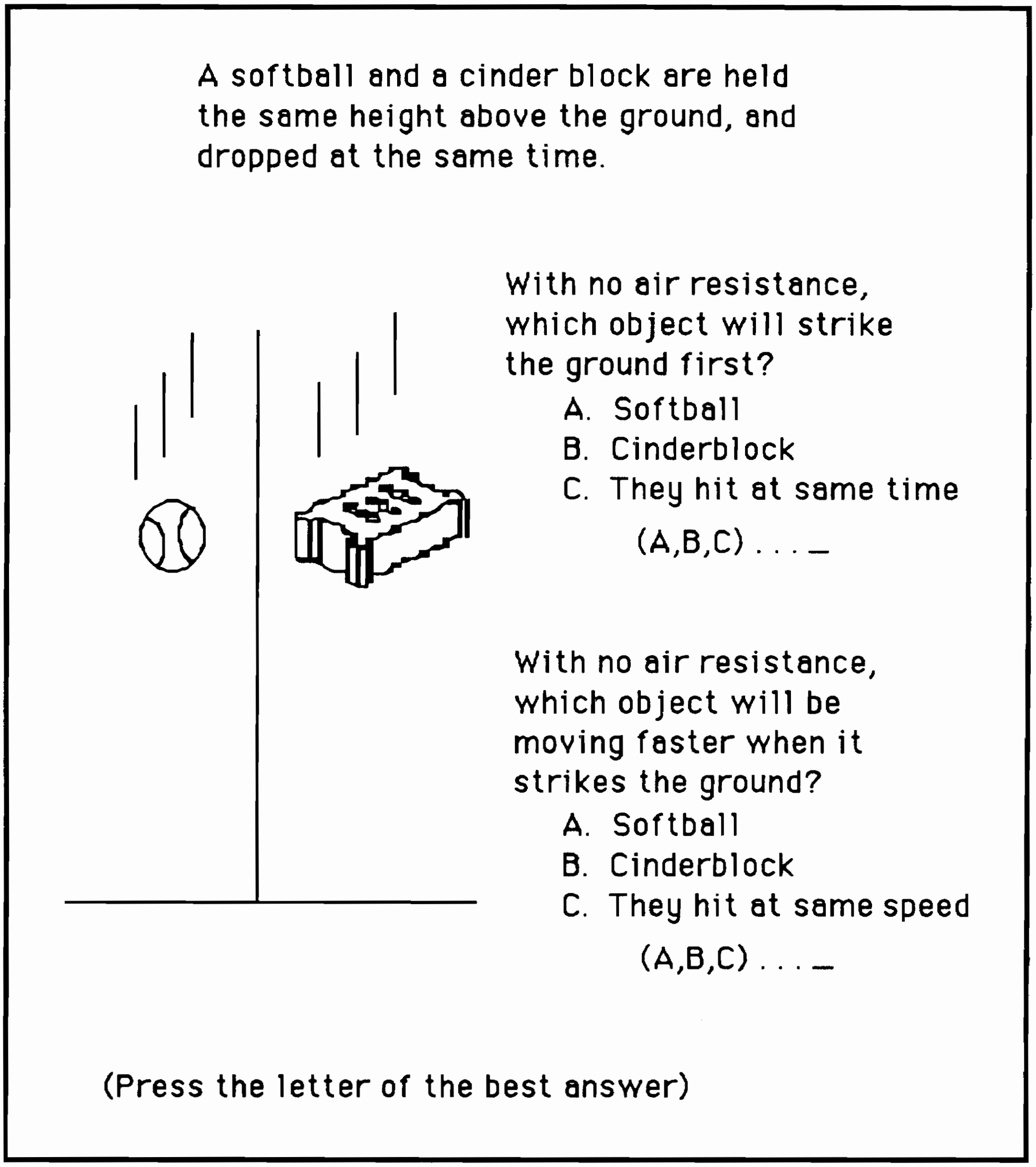
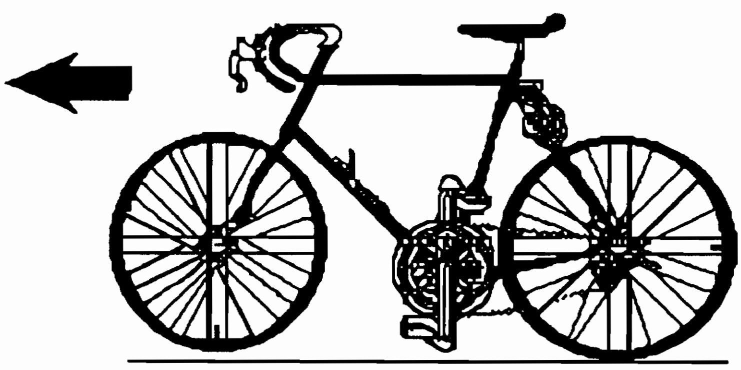


Figure 5. The Softball-Cinderblock Falling question on the final version of the computer Selection Test.

The rider has stopped pedalling the bicycle.
The moving bicycle is slowing down.
Why is the bicycle stopping?



A. There is a friction force acting on the bicycle.

B. No force acts on the bicycle, and all objects will stop when no force acts on them.

(A,B) . . . _

(Press the letter of the best answer)

Figure 6. The Bicycle Slowing question on the final version of the computer Selection Test.

The computer system's Selection Test selected *completed* students for treatment on the basis of possession of one or more of the above three alternative conceptions. The Selection Test questions are shown in Figures 1-6. The selected students were randomly assigned to an experimental group and a control group. The reliability of the diagnostic test was estimated by a *coefficient of internal consistency* which was computed from the Selection Test scores of the *completed* students by *Cronbach's alpha* (Crocker & Algina, 1986). The effectiveness of the remediation simulations (see Figures 7 and 8) in inducing conceptual change by the experimental group of *completed* students was estimated by comparing the mean score of the experimental *completed* group on the computer posttest to that of the control *completed* group, by means of a *t test for independent samples*.

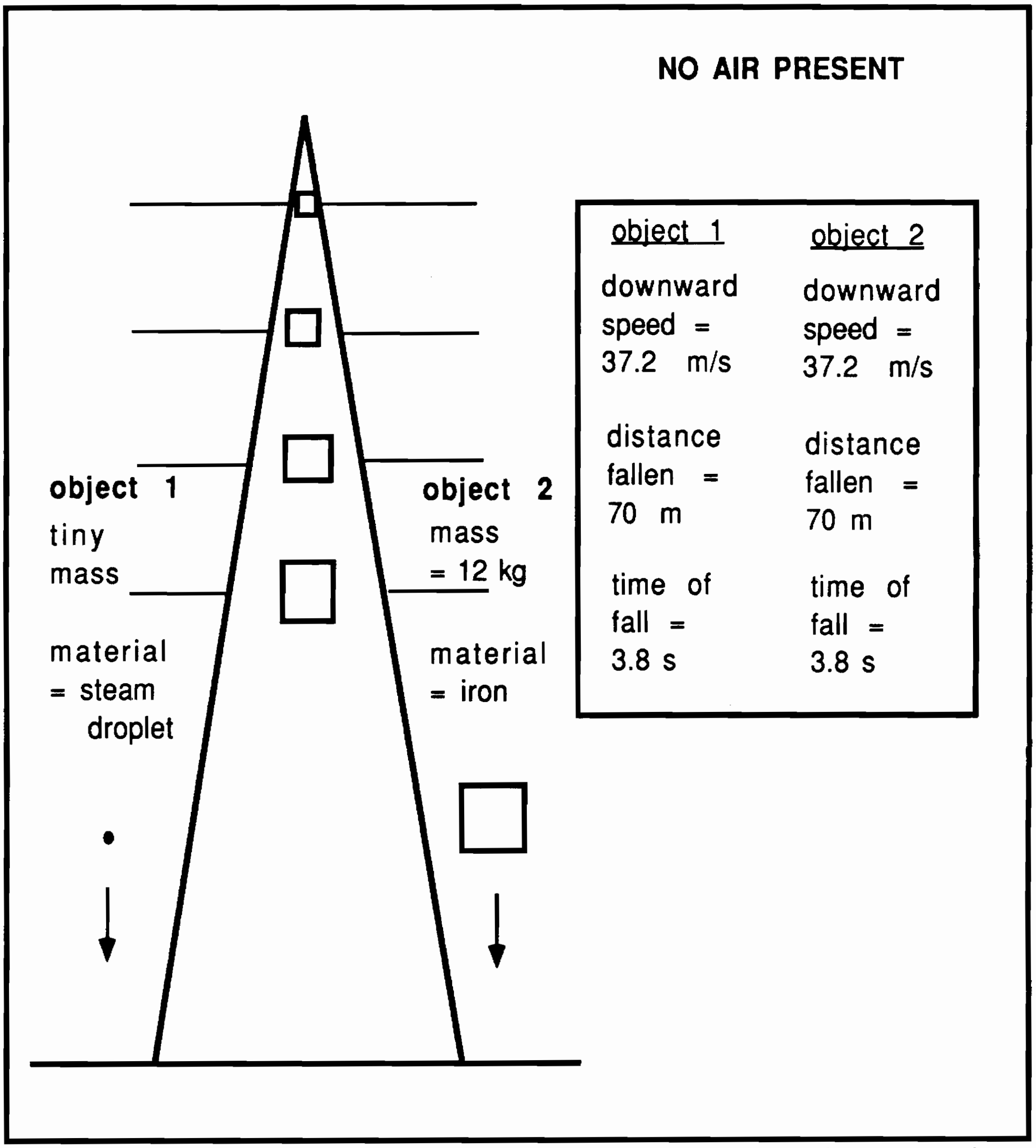


Figure 7. The Objects Falling/Rising simulation. Two objects rise or fall on opposite sides of a tower. Air is alternatively present or not present in successive runs of the simulation.

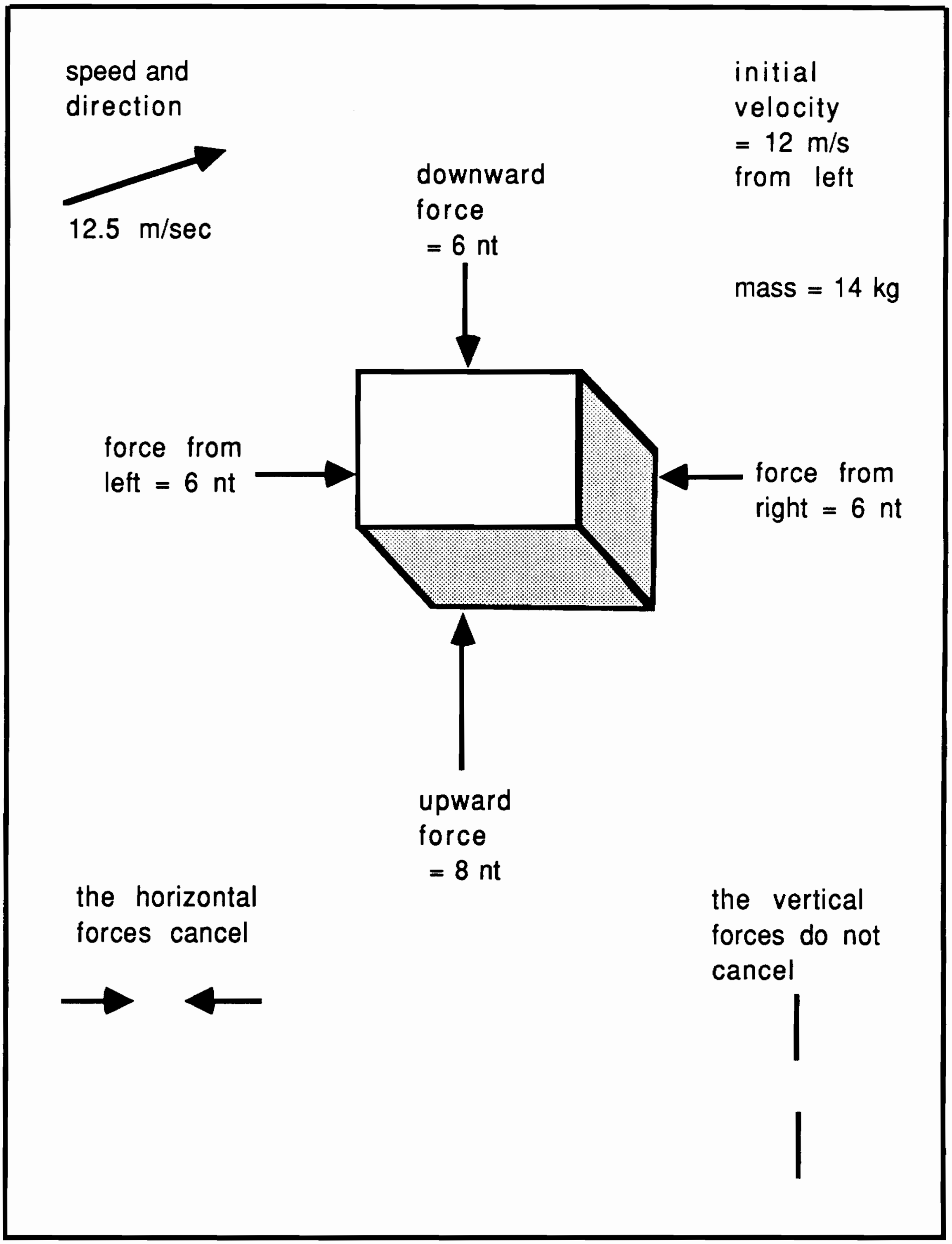


Figure 8. The Cube Moving simulation. As the cube moves, the incident forces and the current speed and direction are always shown. After the start of the simulation, the initial velocity, mass, and force-cancellation diagrams disappear.

Design

The design for the present investigation is shown schematically in Figure 9. After the pilot studies were completed and the final version of the computer Selection Test had been written, a sample of five eighth-grade physical science students was given structured interviews similar to Osborne and Gilbert's (1980) "interviews about instances." Each student was interviewed alone. The picture for each of the Selection Test questions (Figures 1-6) was shown to the student. The interviewer asked each student to describe what he or she thought was happening in the picture, and to explain why it was happening. At this, and each stage of the interview, the interviewer tried steadily (but gently) to urge the student to continue the explanation. The interviewer did this without volunteering information concerning the concepts being discussed and without leading the student toward any certain type of answer. At no time during the interview did the interviewer evaluate whether the student had an acceptable scientific concept. He tried only to establish what the student's views were, however *unscientific*.

After the student's explanation for the picture had been given, the interviewer showed the student the question for the picture and asked the student to read it. Then the interviewer asked the student to explain various words in the question, as well as to explain the question. Finally, the student was asked to answer the question. The interviewer continued each question by showing the student each answer for the question in turn, then asking the student if he or she would choose that answer and to explain why he or she would choose it Based on the structured interviews, a small number of final changes were made in the wording of the Selection Test questions.

Then the final version of the computer Selection Test was administered to 60 eighth-graders from two schools. These were students who had studied force and motion several months earlier in their science classes (i.e., the *completed* students). The Selection

Test selected 55 students as possessing one or more of the above three alternative conceptions, on the basis of their "errors" (nonscientific answers) to multiple choice questions with accompanying graphics. The selected students were assigned randomly to the experimental group or the control group.

Each of the 27 students in the experimental group ran the Objects Falling/Rising simulation (Figure 7) ten times and the Cube Moving simulation (Figure 8) five times. The 28 control group students did not do the simulations. The control group students filled out questionnaires concerning their attitudes and opinions about the the Selection Test, while the experimental group students worked through the two simulations.

The computer Selection Test was also administered to 36 eighth-graders from a third school, who were currently studying force and motion (i.e., the *in-process* students). This was so that their patterns of "errors" could be compared with the error" patterns of the *completed* students from the two other schools.

The experimental and control groups of *completed* students were both administered the computer posttest. A schematic summary is shown in Figure 9 of how the various types of data that were obtained in the present study have been analyzed and employed. The posttest answers of the *completed* students served as evidence of any immediate alteration in the students' alternative conceptions which had been facilitated by the simulations. The posttest scores of the experimental group students were compared with those of the control group students by means of a *t-test for independent samples.*

The science teachers of the completed students were asked to rank each student according to his or her achievement in science class. This was to determine whether any correlation existed between a student's degree of science achievement and his or her possession of one or more of the above three alternative conceptions. The ranking categories were: *top 1/3 of the class*, *middle 1/3*, or *lowest 1/3*.

To determine whether working through the computer simulations had facilitated any long-term changes of the alternative conceptions of the experimental group, a sample of 26% of the students (i.e., 7 pupils) was administered a Retention Test 1.5 months after the students had initially used the simulations. Three students took the Retention Test on the computer; four took it with pencil-and-paper. After they had taken the Retention Test, they were interviewed briefly on their understanding of the simulations and their changed conceptions.

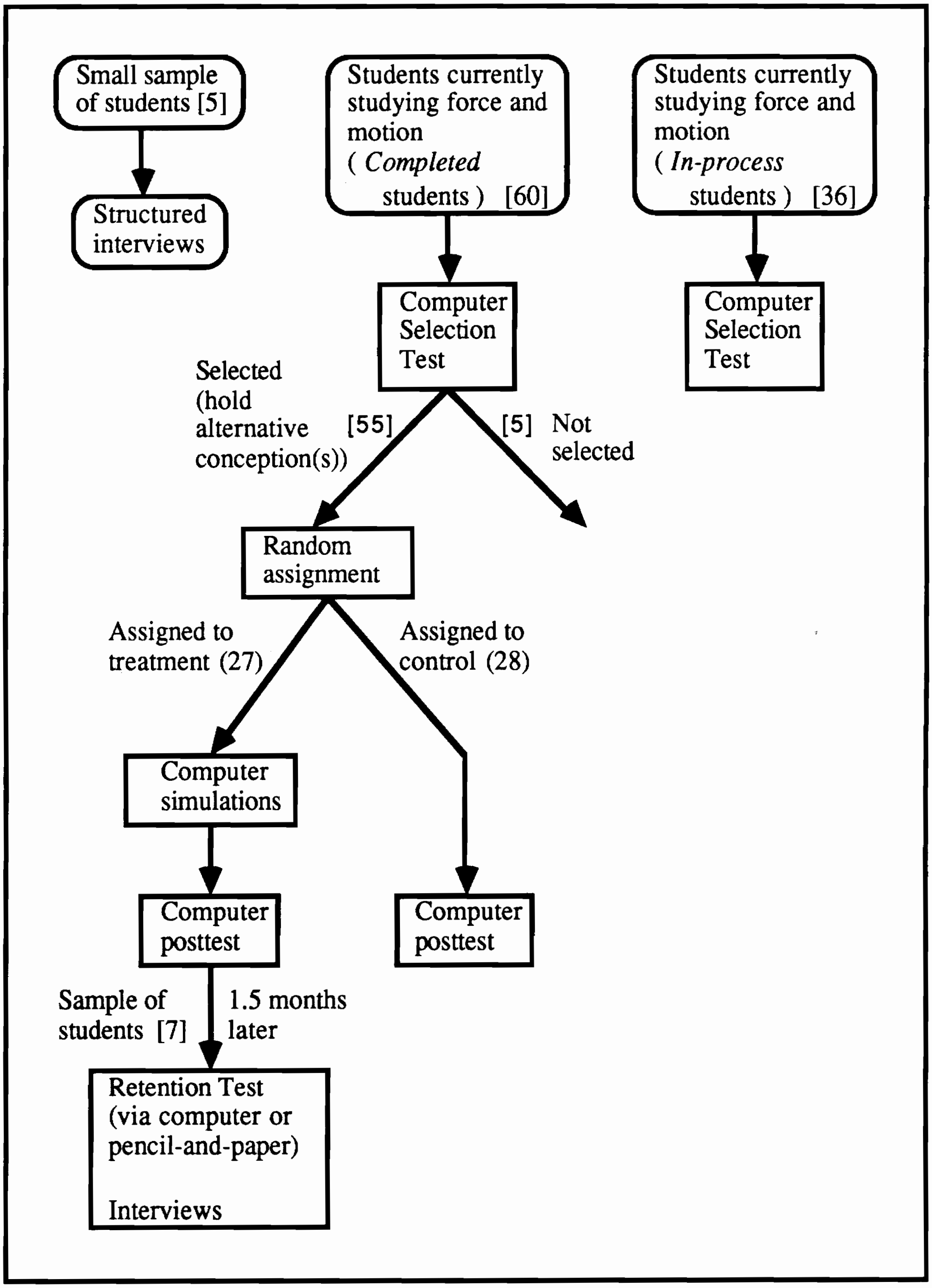


Figure 9. Schematic diagram of the design of this investigation.

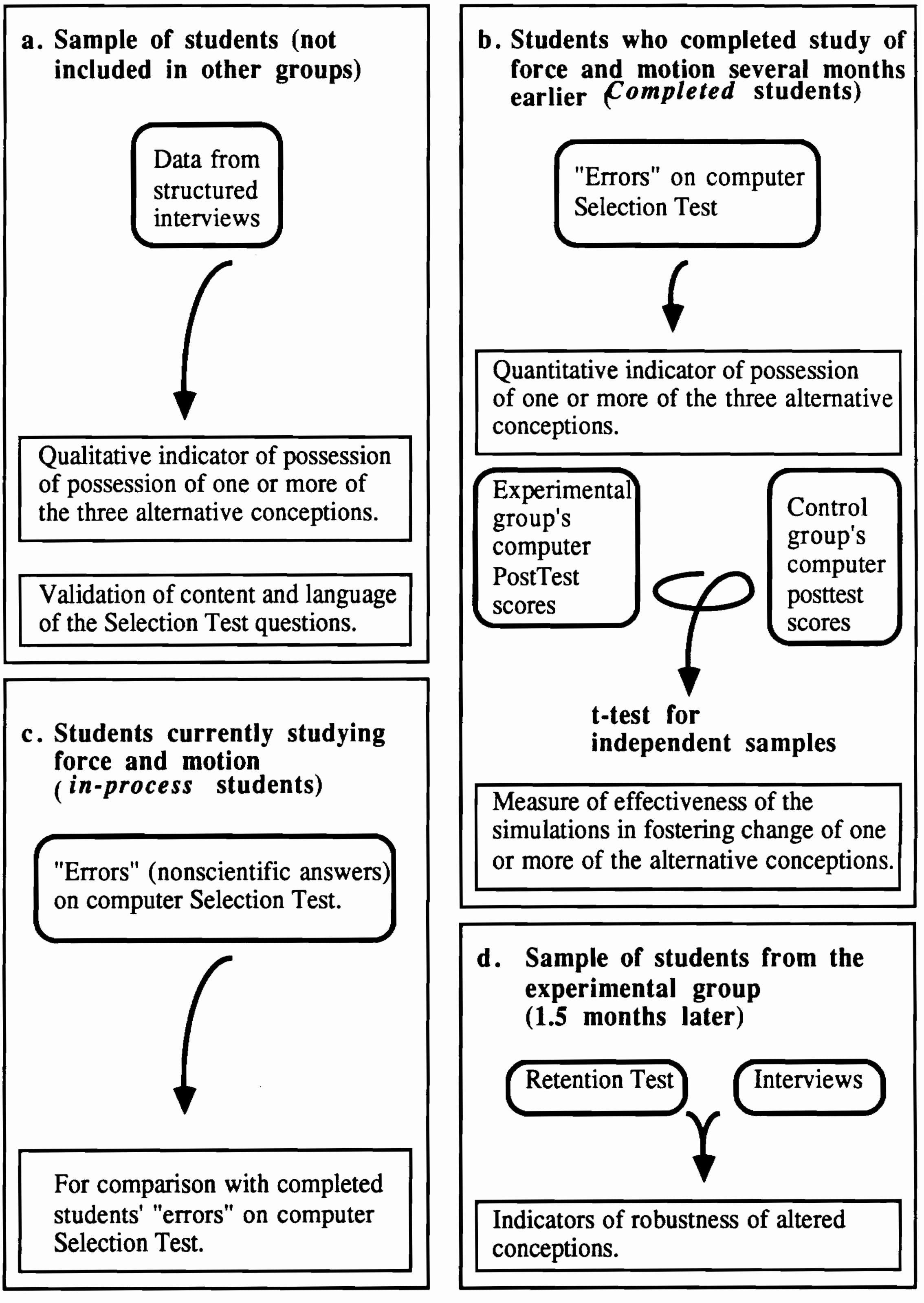


Figure 10. Schematic summary of the data treatment for this investigation.

Chapter 4

RESULTS AND DISCUSSION

Students' possession of the alternative conceptions: Evidence from structured interviews

Five 8th-graders were interviewed. The statements of four students (Eddie, Tom, Anne and John) indicated that each possessed one or more of the alternative conceptions # 1 - 3a. None of the five students possessed conception # 3b. The conversation of Lyle, the fifth student, provided no evidence that he possessed any of the alternative conceptions.

The alternative conceptions, listed here again, are all contrary to the concepts of force and motion that are taught in 8th-grade physical science.

1) *Quickness of fall depends on mass* conception

    With no air resistance, the downward movement of a more massive object is faster than that of a less massive object.

2) *Unbalanced force* conception

    If an object is moving and no unbalanced force is acting on it, the object will come to rest.

3) *Direction of vertical movement depends on type of material* conception

    a) Light objects rise because they are made of material which naturally tends to move upward; b) heavy objects fall because they are made of material which naturally tends to move downward.

In this sample of 8th-graders, a student's possession of an alternative conception was unrelated to whether the pupil was a strong or weak learner of 8th-grade science. Pupils at all levels of science-learning ability possessed alternative conceptions. Eddie, whom the teacher rated in the top third of the science class, actually possessed some form of the three alternative conceptions, # 1 - 3a. Tom, also rated in the top third, possessed one alternative conception. Anne and John, rated in the lowest third of the science class, each possessed one alternative conception. Lyle, rated in the middle third, had none of the alternative conceptions.

In particular, Tom and Eddie each evidenced possession of a *quickness of fall depends on mass* conception. When Tom was shown the Cinderblock-Softball Falling picture (Figure 5) during the interview, he said that the cinderblock will strike the ground before the softball because "It [the cinderblock] will be heavier ... more mass ... It [gravity] makes it fall faster." Eddie had a more complicated alternative conception. When presented the Anvil-Can Falling picture (Figure 3), he said that "... the aluminum can will fall faster, but the iron can would have more mass and it would catch up."

Eddie and Anne each possessed an *unbalanced force* alternative conception. When Eddie was shown the Cup Sliding picture (Figure 4), he said that if the steady pull with the string is balanced by the force of friction between the cup and the tabletop, then "... the cup would stay in the very middle. The cup would stay where it is and would not move." In her conversation, Anne used the term *weight* much as a scientist would employ the term *force*. When Anne was shown the Bicycle Slowing picture (Figure 6), she said that the bicycle was slowing down "Because the person has stopped pedaling, and there's really no weight on it to do anything if it was pedaling ..."

John and Eddie possessed *direction of vertical movement depends on type of material* alternative conceptions. When John was shown the Steam Rising picture (Figure 1), he said that gravity applies " ... on solids," but not not to steam. In fact, he explained that gravity does not apply to gases, with the consequence that they rise. While discussing the same picture, Eddie said that the steam rises because "... it's not really a push that's sending it up. It's just a natural tendency to go up ... Just what it normally does."

Although the conversations of four of the students provided evidence of the possession of one or more of the alternative conceptions, most of each conversation contained statements which were scientific (on an 8th-grade level). This indicated that each student had *woven* his or her alternative conception(s) into a fabric of scientific conceptions.

Students' possession of the alternative conceptions: Evidence from their "errors" on the Selection Test

The sixty 8th-graders from the first and second schools (the *completed* students) took the computer Selection Test several months after they had studied force and motion in their physical science classes. For purposes of comparison, thirty-six 8th-graders from the third school (the *in-process students*) who were currently studying force and motion, also took the computer Selection Test.

On the Selection Test, a student's answers which differed from the scientific viewpoint (i.e., answers which a scientist would term "errors") provided evidence of the student's possession of alternative conceptions. Table 2 shows the percentage of the *completed* students, and the percentage of *in-process* students, who chose each "error" answer. Answers 3A, 3B, 6A, 6B, 7A and 7B had been designed to indicate the possession of a *quickness of fall depends on mass* alternative conception; answers 5A and 8B, an *unbalanced force* alternative conception; and answers 1A, 2A and 4B, a *direction of vertical movement depends on type of material* alternative conception.

Table 1.
Student "errors" on computer Selection Test and associated alternative conceptions

Alternative conception	Question number and part	Description of question	Answer	Percent of students who chose answer: *Completed* students	Percent of students who chose answer: *In-process* students
# 1 *Quickness of fall depends on mass*	3-A	Anvil-Can Falling	Anvil gains speed faster	30	78
	3-B	Anvil-Can Falling	Aluminum can gains speed faster	8	8
	6-A	Softball-Cinder-block Falling	Softball strikes ground first	10	25
	6-B	Softball-Cinder-block Falling	Cinderblock strikes ground first	28	50
	7-A	Softball-Cinder-block Falling	Softball moves faster when it strikes the ground	22	31
	7-B	Softball-Cinder-block Falling	Cinderblock moves faster when it strikes the ground	35	58
# 2 *Unbalanced force*	5-A	Cup Sliding	String's pull is not balanced by another force	33	19
	8-B	Bicycle Slowing	No force acts on bicycle, so it stops	37	47
# 3 *Direction of vertical movement depends on type of material*	1-A	Steam Rising	Droplet material rises naturally	70	33
	2-A	Spoon Falling	Steel moves down-ward naturally	0	0
	4-B	Why anvil falls	Iron moves downward	2	3

Comparison of the "errors" on the Selection Test made by the *completed* students with those of the *in-process* students (Table 1), revealed an "error profile" for the students who had completed their study of force and motion which was very different from the "error profile" of the students currently studying that topic. For seven of the "error" answers, larger proportions of the *in-process* students answered nonscientifically than did proportions of the *completed* students. For two "error" answers, the same proportions of *in-process* students and *completed* students answered nonscientifically. For two "error" answers, smaller proportions of the *in-process* students answered nonscientifically.

The differences between the "error profiles" of the *in-process* students and the *completed* students may reflect the fact that many of the *in-process* students were in transitional periods of learning force and motion, with their alternative conceptions interacting in unpredictable ways with the scientific conceptions which were currently being presented to them in science class. The different "error profile" of the *completed* students suggested that several months after completion of the force-and-motion unit, an "error profile" of the *in-process* group's answers would likely show lower proportions of students for several of the "error" answers categories.

The Selection Test indicated that a large portion of the *completed* students apparently possessed a *quickness of fall depends on mass* alternative conception. For the Can-Anvil Falling question (Figure 3), 30% of these students answered that the iron anvil would gain speed faster. Only 8% answered that the aluminum can would gain speed faster. For the first Softball-Cinderblock Falling question (Figure 5), 28% of the *completed* students answered that the cinderblock would strike the ground before the softball. Only 10% answered that the softball would strike first. For the second Softball-Cinderblock Falling question (Figure 5), 35% of the *completed* students answered that the cinderblock would be moving faster when it struck the ground than would the softball. Only 22% answered that the softball would be moving faster when it struck the ground.

The test also indicated that a large portion of the *completed* students possessed an *unbalanced force* alternative conception. For the Bicycle-Slowing question (Figure 6), 37% of these students thought that the bicycle was stopping because no force was acting on the bicycle and all objects will stop when no force acts on them. For the Cup-Sliding question (Figure 4), 33% of the *completed* students felt that the cup slides across the table with a constant speed because the pull on it by the string is not balanced by another force.

Finally, the test indicated that nearly three-quarters of the *completed* students (70%) possessed a *direction of vertical movement depends on type of material* alternative conception when they thought about rising steam. However, no *completed* student answered that a spoon falls because steel is a material which moves downward naturally. Only 2% of the *completed* students (i.e., one person) thought that an anvil falls, instead of rises, because iron is a material which moves downward naturally.

The intercorrelations between the answers of the *completed* students to the Selection Test questions (Table 2) were examined for indications of which conceptions of force-and-motion these students linked in their thinking. Answers to the first Can-Anvil Falling question (Figure 3) were correlated moderately (0.58 and 0.48, respectively) with answers to the Softball-Cinderblock Falling questions (Figure 5). There was an even stronger correlation (0.67) between answers to the first Softball-Cinderblock Falling question and answers to the second one. These three questions involved the fall of objects of different mass with no air resistance. The similar response patterns for these three questions suggested that many students, while pondering each of them, may have evoked the same or linked conceptions.

Table 2.
Item intercorrelation matrix for answers of the *completed* students to the computer Selection Test

		1	2	3	4	5	6	7	8
Item 1	Steam Rising	1.00	0	-.16	-.20	0	.07	.09	.05
Item 2	Spoon Falling		1.00	--	--	--	--	--	--
Item 3	Can-Anvil Falling			1.00	.17	.05	.58	.48	.25
Item 4	Why Anvil Falls				1.00	.18	.17	.11	-.10
Item 5	Cup Sliding					1.00	-.12	-.31	.27
Item 6	Softball-Cinderblock Falling						1.00	.67	.18
Item 7	Softball-Cinderblock Falling							1.00	.25
Item 8	Bicycle Slowing								1.00

There was a very slight correlation (0.27) of answers to the Cup Sliding question (Figure 4) with the Bicycle Slowing question (Figure 6). These two questions involved the horizontal motion of an object upon which all incident forces were balanced. This low correlation suggested that only a small proportion of the students, while contemplating these two questions, evoked the same or linked conceptions.

Answers to the Steam Rising question (Figure 1) did not correlate to a significant degree with answers to any other question, including the Spoon Falling (Figure 2) and Why Anvil Falls (Figure 3) questions. This suggested that while they pondered the rise of objects, the *completed* students did not evoke the same or linked conceptions as they did when they considered the fall of objects. The fact that none of the *completed* students chose a nonscientific answer to the Spoon Falling question resulted in the lack of correlations between it and any other question.

There were no other significant correlations between the answers of the *completed* students to the Selection Test questions.

The Cronbach's Alpha coefficient (Crocker & Algina, p. 142, 1986) was calculated in order to obtain an estimate of the internal consistency of the Selection Test items for the group of *completed* students who were selected. It's value of 0.51 can be considered as a lower bound to a theoretical reliability coefficient, the *coefficient of precision* , for the test (Crocker & Algina, p. 142, 1986). The value of the reliability was slightly lower than the author had anticipated. However, the reliability of a test decreases: a) for increased homogeneity of the group of examinees, b) for decreased test length, and c) when the test is too difficult or too easy for a group of examinees (Crocker & Algina, pp. 143-146). It is likely that the ease of the Spoon Falling and the Why Anvil Falls questions for the *completed* students had a reductive effect on the Selection Test reliability.

The student's answers in the structured interviews, had suggested that a pupil's possession of an alternative conception was unrelated to whether the pupil was a strong or weak learner of 8th-grade science. To obtain further evidence concerning the existence or nonexistence of any such relation, the *completed* students' scores on the Selection Test were correlated with the teacher rankings of the students on the basis of their achievement in 8th-grade science. The calculations yielded a Pearson product moment correlation coefficient of 0.24, which indicated that there was a relatively weak linear relationship between the science learning achievement of a *completed* student and the possession of alternative conceptions.

Immediate effect of working through the simulations

For the *completed* students (who had studied force and motion several months earlier in physical science class), the scores on the computer posttest made by the experimental group and the control group are compared in Table 3. The students in the experimental group answered an average of 5.9 questions correctly on the PostTest, with a standard deviation of 1.5 question; the control group students, an average of 4.8 questions correctly, with a standard deviation of 1.8. A *Student's t test for independent samples* showed that the experimental mean was significantly superior to the control mean ($t=2.64$, $p=0.005$).

Table 3
Comparison of experimental and control group scores on the computer posttest

Experimental group			Control group		
M	SD	N	M	SD	N
5.9	1.5	27	4.8	1.8	28

Note The maximum possible PostTest score was 8.

The sample size for the experimental group (27) was not equal to that of the control group (28). When sample sizes are unequal and the *Student's t test for independent samples* is employed (as above) to test equality of group means, the variance of the population sampled by one group must be equal to the variance of the population sampled by the other group(Hinkle, Wiersma, & Jurs, 1979, p. 209). If these variances are not equal (i.e., are not *homogeneous*), special procedures must applied to test the equality of the means. The variance was found to be *homogeneous* by an *F* test (F=1.37, alpha=0.05), so special procedures were unnecessary.

Although the students participating in the present study were randomly assigned to the experimental or control groups, their selection from a larger population of 8th-graders was not truly random. Students were selected to participate for such reasons as: they had returned their parent permission slips, their teachers required them to participate, and/or they were present at school on the day of the study. For non-random selection of students, a statistical test should be applied which permits statistical inference about treatment effects on the basis only of random assignment to treatments (Hinkle, Wiersma,

& Jurs, 1979, p. 200). Such a *randomization test*, the Mann-Whitney U-test, showed the experimental mean to be significantly better than the control mean ($z=2.38$, $p=0.009$).

The superiority of the experimental group's performance on the computer PostTest was, therefore, attributable to working through the simulations. The simulations had been designed using conceptual change strategies which were based on the premise that a student could be facilitated in supplanting alternative conceptions with the appropriate scientific conceptions by *playing the game of science* with situations that epitomized scientific idealizations (or exemplars). The significant immediate-effect on the experimental students of working through the simulations indicated that there was merit in this approach to conceptual change.

Of further interest was whether working through the simulations had any long term effect on the experimental group students.

Long-term effect of working through the simulations

To check for the students' long-term retention of the simulation-induced change of alternative conceptions, a sample of seven pupils from the experimental group was retested 1.5 months after they had worked through the computer diagnosis-and-remediation program. Students were chosen who had answered scientifically on at least one question on the PostTest that they had answered nonscientifically on the Selection Test. Six of the students in the sample had answered one more question *correctly* on the computer PostTest than on the computer Selection Test; one student had answered two more questions *correctly*.

As a Retention Test, the seven students were administered the original PostTest again. Three students took the Retention Test on the computer, four took it as a pencil-and-paper test. Considering their total scores, five students scored the same on the Retention Test as they had originally on the computer PostTest. Three of these five students took the Retention Test on the computer; two took it on paper. The sixth student, who took the Retention Test on paper, scored one less on the Retention Test than on the original computer PostTest. The seventh student, who also took the Retention Test on paper, scored three less on the Retention Test than on the original PostTest.

Considering the specific question which each of six of the students had originally answered *non-scientifically* on the computer Selection Test and *scientifically* on the computer PostTest, the six students each answered the same question *scientifically* on the Retention Test. The student who had originally answered two more questions *scientifically* on the computer PostTest than on the computer Selection Test, answered one of the two questions *scientifically* on the Retention Test.

To sum up the long-term effects: a) 5 of 7 of the students in the sample scored the same on the Retention Test as they had originally on the computer PostTest, and b) all but one of the answers which the seven students had "corrected" after working through the simulations were retained 1.5 months later on the Retention Test. Thus, the conceptual-change effect of working through the simulations was robust over time for the students in the sample.

Conclusions

The present investigation could be summed up in the following three sentences. Eighth-grade science students who were diagnosed as possessing alternative conceptions by the computer Selection Test were allowed to work through two computer simulations.

Working through the two simulations of the diagnosis-and-remediation system, simulations which had been designed according to the author's science conceptual change theory, did facilitate the students in altering their alternative conceptions to a significant degree. The computer posttest supplied evidence of the students' short-term conceptual change, and the Retention Test supplied evidence of robustness of the change.

However, this *skeletal* summary omits a great deal of the substance of the investigation: the supporting conceptual change theory, structured interviews of 8th-graders, construction and validation of the Selection Test, "error profiles" of the *completed* and *in-process* students on the Selection Test, and construction of the simulations. Brief attention to these aspects of the investigation at this point will not only *flesh out* the body of the study, but will also serve to position the study a bit in relation to the earlier science conceptual change studies by other researchers upon which it has been built.

As the present study unfolded, a portion of the findings reconfirmed results of earlier investigations by other researchers. This was indicative that the present investigation was on the right track. More accent may have been placed by the author upon examining the "errors" of the students as a key to their science-learning difficulties, than has been placed by some earlier researchers. The rationale behind the employment of the computer simulations as an intervention tool, including the author's conceptual change theory, differed in certain aspects from the rationales of earlier researchers who have employed computer interventions to facilitate conceptual change in science.

The important theoretical paper of Posner et al. (1982) on science conceptual change provided the starting point for the author's search for an applicable theory of instructionally eliciting science conceptual change. However, this paper became also the point of departure for the author's construction of a model of conceptual change which would be applicable to the facilitation of a student's alteration of only a small number

(1 - 3) of alternative conceptions. The author accepted the argument of Posner et al. that science educators can derive analogous hypotheses for a student's conceptual change from the descriptions of patterns of conceptual change in scientific communities by contemporary philosophers of science such as Thomas Kuhn. However, the author's notions of a science student's conceptual change differed with Posner et al. in two critical respects: a) the author did not share the commitment of Posner et al. to learning being a purely *rational* activity, and b) the author surmised that to address a very small number of a student's alternative conceptions in a short period of time, one could not hope to bring about an entire *scientific revolution* in the pupil's thinking. Rather, a more reasonable (and less ambitious) expectation seemed to be to draw the student's attention to his or her alternative conception(s) by exposing the student to a phenomenon anomalous to the naive conception(s) and allowing him or her to investigate the phenomenon several times in ways which would provide him with clues to the *more scientific* conception(s).

The structured interviews undertaken in the present study added evidence to that previously provided by (Driver & Easley, 1978) that a student's possession of alternative conceptions is unrelated to whether the pupil is a strong or weak learner of science. This was further confirmed by the finding of a low correlation between the scores of the completed students on the Selection Test and their rankings on achievement in science class by their teachers.

The structured interviews also provided evidence that a student who has studied force and motion links alternative conceptions within a conceptual framework that often contains many *more-scientific* conceptions. Other researchers have found that students beginning a science course typically have a large number of interrelated common-sense intuitive ideas based on years of experience with moving objects, comprising a belief system that is quite different from the formal system of Newtonian mechanics (e.g., see Champagne, Klopfer and Anderson, 1980). The results of the present study indicate that the student integrates the conceptions that he or she learns in the science classroom as best the student can with his or her framework of previous conceptions. This adds support to the findings of Champagne et al. (1980) that some students assimilate new knowledge into their old system of naive beliefs using very sophisticated rationalization.

During the construction and validation of the Selection Test, it became apparent that the language and content of some questions and answers were at the level of sophistication of introductory physics, rather than 8th-grade physical science, and had to be altered. While investigating via structured interviews the appropriateness for 8th-graders of the Selection Test questions and answers, the author found also that the content and form of some of the graphics for the Selection Test questions were not appropriate for 8th-grade girls and boys. Since the students apparently responded most readily to pictures of items which were not *laboratory-like*, all inclined planes, ring-stands, and beakers were eliminated from the pictures. An interesting area for further research would be the influence of the degree of *laboratory-like-ness* of the content and language of science achievement questions upon the student's accessing of naive or *more-scientific* conceptions while answering the questions.

When the results of the Selection Test were considered, the differences between the "error profiles" of the *completed* and *in-process* students indicated that many students possess more naive conceptions at the beginning of the study of a unit such as force and motion than they do after completing the unit. However, the "error profile" of the *completed* students showed they still hold many alternative conceptions after completion of the unit. An interesting area for further research would be to investigate the possibility that while studying the unit on force and motion the students' possession of alternative conceptions is in a transitional period, wherein their "error profile" would differ from that exhibited either before starting the unit or following the unit. This might enable the researcher to determine which alternative conceptions are more persistent through the classroom instruction, and which are less persistent.

The interesting findings of the "error profiles" vindicated the *neoconstructivist* approach of this investigation, wherein the students' deviations from the expected path of the teacher (or of the textbook) have illuminated how the students were organizing their frameworks of conceptions of force and motion.

The moderately large intercorrelations between the *completed* students' answers to the Selection Test questions which dealt with falling objects suggested that the test was satisfactorily diagnosing *quickness of fall depends on mass* alternative conceptions. However, the very slight intercorrelation between answers to the two questions dealing with objects moving horizontally with all incident forces balanced, suggested that these two questions (which were intended to diagnose *unbalanced force* alternative conceptions) may not have been *aimed at* the same student conception.

Although in the pilot studies the answers of a few students had provided evidence that they believed that heavy objects fall because they are made of material which naturally tends to move downward (alternative conception 3 b), only one *completed* student answered in this manner on the final version of the Selection Test. However, the answers of many *completed* students provided evidence that they believed that light objects rise because they are made of material which naturally moves upward (alternative conception 3 a). It seems likely that conceptions 3a and 3b should be considered as two distinct alternative conceptions.

The fact that a student's possession of an alternative conception was unrelated to whether he or she was a strong or weak learner of 8th-grade science (as shown by the structured interviews and the Selection Test), has at least three important implications for the science educator. First, it suggests that science teaching is not *reaching* the strong learner in the same areas of instruction where it is not *reaching* the weak learner. Second, it indicates that the science teacher cannot assume that because a student is a strong learner, he or she need not be examined for alternative conceptions. Third, it suggests that the same diagnosis-and-remediation system might be used to locate alternative conceptions of both strong and weak learners, and to facilitate their alterations by the students.

A corollary implication of the first implication above (that science teaching may be *missing* the strong learner in the same way that it is *missing* the weak learner) might be that alternative conceptions are accessed equally frequently by strong and weak learners of science. An argument against accepting this corollary could be that : a) the gentle, but persistent, probing of the structured interviews merely caused the strong students to pass through one or more *layers* of newly-acquired scientific conceptions to a *deeper layer* of older, less frequently used naive conceptions; while b) the structured interviews merely probed the weak learners' *top layers* of conceptions, layers which contained naive conceptions which are frequently used. However, comparison of the structured interview results with those of the Selection Test provides an argument for accepting the corollary. It is unlikely that the Selection Test questions (multiple choice questions with graphics) would probe the strong learners' conceptual systems more *deeply* than those of the weak learners. So the low correlation of *completed* students' scores on the Selection Test with their teacher rankings seems to indicate that strong learners access naive conceptions as readily as do weak learners. This might be an interesting area for further study.

During the construction of the remediation simulations, a great deal was learned about the instructional design aspects of this computer-based intervention. It is the author's impression that the design details of instructional interventions are too often absent from studies reported in the science education literature. While not discussed in this report, a more complete discussion of the instructional design considerations involved in the present study can be found in the author's paper (Weller, 1990).

In some respects, it was surprising that the computer diagnosis-and-remediation system had the significant immediate effect and long-term effect of fostering the alteration of students' alternative conceptions. This is because: a) the motivation and concentration of the *completed* students who participated in the study were probably not much above minimal, and b) the present study employed only a *snapshot* manner of looking at the students' alternative conceptions at different *points* in time. For this study, the students were taken out of their normal daily classroom routine and environment, and asked to sit at microcomputers either in the corner of a classroom laboratory or of a library. In these locations, the distractions to the students were certainly equal to or greater than those that they usually experienced in their classrooms. Also, although the students' motivation did appear to be rather high, it could have been not much different than the minimal recognition required of the pupil in the typical teaching situation. Furthermore, this investigation looked at the student's possession of alternative conceptions of force and motion at three *points* in time: at the administration of the Selection Test, the posttest, and the Retention Test. This *snapshot* approach to monitoring the student's conceptions did not look at the process by which a student altered his or her conceptions of force and motion through time. Due to the positive results of the study despite these distractions, the author is tempted to surmise that a much larger than 1.1 average immediate differential between the experimental and control students could be obtained if: a) the diagnosis-and-remediation system were integrated into the students' normal classroom routine and environment, b) the system were used repeatedly by the students, and/or

c) the system were modified so that it monitored the process by which a student altered his or her conceptions (or the system were used in conjunction with such monitoring). These are, of course, three likely areas for further research.

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APPENDIX A:

SAMPLE TRANSCRIPT FROM PILOT STUDY INTERVIEWS

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SAMPLE TRANSCRIPT FROM PILOT STUDY INTERVIEWS

Interview with Martin **March 16, 1990**
at an urban public Middle School.

Note: The interviewer's statements are prefaced by *Int*. Martin's statements are prefaced by *M*. Martin is not actually the student's name. The interviewer had pictures on paper of all nine questions and of the two simulations. The interview was conducted about fifteen minutes after the student had done the diagnosis-and-remediation program.

Interviewer turns on the tape recorder.

M: Martin.

Int: Martin. OK. Did it [the computer program] tell you that you improved, stayed the same, or did worse--at the very end there?

M: It improved.

Int: Improved? Do you remember how many?

M: I think it was two.

Int: If I had to have you guess which ones do you think you got better on--what ideas do you think you got better on?

M: Um.

Int: What did you miss at first and do better on later?

M: I think I missed--um--why the fumes rise, and uh.

Int: [The interviewer indicates the Steam Rising question.]

M: Yeah.

Int: The spoon? [The interviewer indicates the Spoon Falling question.]

M: Yeah.

Int: Or not?

M: No, I got--I think I got that one right.

Int: Oh. "Why the fumes rise," and what was the other one?

M: The--the bike. "Why--why would it stop?" [The student is referring to the Bicycle Slowing question.]

<u>Int</u>: Oh. OK. So. What would you think is the--is the better idea now? With the "fumes," what did you put before, do you think?

<u>M</u>: Um, because they belong in the air. [The wording of one answer to the Steam Rising question at this time was that the vapor rises because "It belongs in the air."]

<u>Int</u>: Uhuh. What did you change it to now?

<u>M</u>: No. That's what I put. That's what I put the second time.

<u>Int</u>: Oh. That's what you put the second time. What do you think you put the first time?

<u>M</u>: I don't know.

<u>Int</u>: You don't know. OK. How about the bicycle? [The interviewer refers to the Bicycle Slowing question.] What do you think you put first, and what do you think you put that was better?

<u>M</u>: Um. The second time, I said--um--'cause it'll--I think. I can't remember what it said, but ...

<u>Int</u>: Oh, I've got it. I'll show it to you. [Interviewer shows Bicycle Slowing question to Martin.] Oh, there are just two possible answers.

<u>M</u>: I put that one. [Martin indicates the scientific answer, that the bicycle slows because "There is a friction force acting on the bicycle.]

<u>Int</u>: You put that one at the first?

<u>M</u>: Yeah.

<u>Int</u>: OK. And then the second time you must have changed it to the other one? [Other answer, that "No force acts on the bicycle, and all objects will stop when no force acts on them."]

<u>M</u>: Yeah.

<u>Int</u>: OK. Um. Now, remember these simulations? You remember the first simulation here? [The interviewer indicates the Objects Falling simulation.]

<u>M</u>: Yeah.

<u>Int</u>: What do you think that it was trying to make for its point--just in your own words?

<u>M</u>: That all the things are gonna fall at the same speed. And land at the same time.

<u>Int</u>: No matter what?

<u>M</u>: Yeah.

Int: OK. That's not bad. Did you run it [the Objects Falling simulation] with and without the table?

M: No. I just ran it with the table.

Int: With the table. Oh. OK. Um. Do you remember this simulation? [The interviewer indicates the Cube Moving simulation.] Where this is--it [the cube] was moving across the screen. What did you think was the main point of that one?

M: I--I don't know.

Int: You couldn't really figure it out?

M: Uh uh. [No.]

Int: Maybe there were more than one main ideas. Did you try to make your forces cancel out--like that hint? [The interviewer is referring to the hint that appeared before the Cube Moving simulation, suggesting that the student try to choose the forces upon the cube so that they would cancel.]

M: Uh uh. [No.]

Int: You didn't try that, huh? Uh, so you can't ... uh. You see, I've wondered about that one, too. The second one [simulation] is a little harder. So you don't really know what the main idea they were trying to get over with that one, huh? OK. Let's see what else have we got. [The interviewer shuffles the papers.]

Int: OK. In your own words, "Martin's Law." Um. I'm going to ask you about three different things. If we drop a light object and a heavy object at the same time from the same height, which will hit the ground first?

M: The heavy object.

Int: "The heavy object." OK. Which will speed up more quickly?

M: The heavy object.

Int: Second. If all the forces on a moving object--it's already moving, right? And all the forces cancel, what will happen to the motion?

M: It will stop.

Int: "It will stop." Third. Do heavy objects move downward because they belong on the ground, or a different reason?

M: For a different reason.

Int: OK. Um. What reason?

M: Um. 'Cause when you--if you're holding it [an object] and let go of it, the force is gonna bring it down.

Int: Ahah. The force of?

M: Gravity.

Int: Last question. Do tiny, little, light objects move upward because they belong in the sky?

M: No.

Int: Why not? Why do they move upward?

M: Because they want to. [Martin chuckles.]

Int: "Because they want to." [The interviewer chuckles.] OK. That's fine. That's--I was just checking up. And ... [The interviewer turns off the tape recorder.]

APPENDIX B:

SAMPLE TRANSCRIPT FROM STRUCTURED INTERVIEWS

APPENDIX B

SAMPLE TRANSCRIPT FROM STRUCTURED INTERVIEWS

Interview with Tom **March 28, 1990**
at a suburban private K-12 school.

Note: The interviewer's statements are prefaced by *Int.* Tom's statements are prefaced by *T.* Tom is not actually the student's name. The interviewer had pictures on paper of all eight questions: a) with only the picture; b) with the picture and the question; c) with the picture, the question, and the first answer; d) with the picture, the question, the first answer, and the second answer; and, in some cases, e) with the picture, the question, the first answer, and the second answer. These students did not do the computer diagnosis-and-remediation program.

Interviewer turns on the tape recorder.

Int: ... say anything. What's your name?

E: Tom.

Int: OK. Right. OK. Tom, what I'm going to do is--these are questions that I've already put on the computer, but we discovered ... I've been a physics teacher in high school for years and the language was--was aimed at physics students, and this is supposed to be for eighth grade students, and so I'm having to rewrite the whole thing. Right? Because it's not--it uses terms that nobody in eighth grade uses.

Int: So what you're going to do--and I really need you to do it--is you're going to look at pictures like this, and then I'm going to show you some of my questions, you know. But I'm going to take it bit by bit. You're going to tell me in your own words. Now, I don't want to hear, you know--don't pretend that you are "Joe Book," right? I want you to just tell me in your own words what you think is happening every time I ask you. Right? If I ask for a theory, I want "Tom's Theory." You--you understand what I mean?

T: Uhuh. [Yes.]

Int: Because I'm really trying to find out if what I thought was happening when people were doing the computer program, is what's happening. And then, after you guys today tell me this stuff, I'm going to go back and--and transcribe it, which means "type it out," and then I'm going to change the questions, and hopefully that will be my final, final computer thing. And I might even come back here. You might even see me again. OK?

T: OK.

Int: Now. What's going to happen ... And you'll hear me say stupid stuff like "This is a picture of a stove," or something. Right? So that--so that when I go home, I'll know which picture you were looking at.

T: Uhuh. [Yes.]

Int: OK. And that's exactly what I'm going to say. [The interviewer chuckles.] This is a picture of a stove, but I want you, if you would, to tell me ... what's happening. [The interviewer indicates the Steam Rising picture.]

T: OK. I think something's cooking on the stove and steam is coming up from the pot.

Int: OK. That's great. Now, let's look at what I put for the actual question for that. And please read that. [The interviewer indicates the Steam Rising question.]

T: Why do the steam droplets move upward instead of downward?

Int: OK. Now, if you were doing that--just in your own words ... Why do you think that they move upward instead of move downward?

T: Hmmm.

Int: This is "Tom's Theory," you know. I ... You don't have to say what you think is in some book, or something. What do you ... Why do they? Why does steam go up?

T: Well, they don't have anywhere to go in the pot, so they go up out of the pot. I don't know ...

Int: OK. OK. Let me--ask a thing that--that somebody has said. Did you know what that meant, that word meant? [The interviewer indicates the word "droplet" in the Steam Rising question.]

T: Uhuh. [Yes.]

Int: OK. That didn't bother you, right? In your mind, a "droplet" is a what?

T: It's a little drop of water.

Int: OK. Great, fantastic. I thought people might not understand that word. OK. Now, let's see what the next thing is--oops--I need to be working with two piles of ... OK. You said that you thought that it didn't have anywhere to go on the side, so that's why it went up. OK. [I'm] looking for the thing that has the answers for this. These [sheets] are in slightly wrong order. OK. Now, first just let's look at my first answer for "A". OK. And read that one.

T: The droplets are composed of material which rises naturally.

Int: OK. Read "B."

T: The upward pushes on each droplet overcome the downward pushes and pulls.

Int: OK. Now, just take a few seconds and think about that. Which one would--do you think you would put?

T: [The student pauses.] B.

Int: OK. You think you'd put "B," and how about you'd first tell me why ...

T: Well, I don't know ... [The student acts like he wants to change his previous answer of "B."]

Int: OK. You're allowed to change your mind. Think about it. What I'm going to ask you is why you put that one, and why you thought the other one--you know--bothered you so you didn't put that one. You can change. Which do you think you'd put, "A" or "B."

T: ... be hard.

Int: It's a toughy, huh?

T: Uhuh. [Yes.] [The student pauses a long time.]

Int: Well, let's think it out, then. Ummm. Just go back to what you said about why the steam went. OK? Now, it couldn't get to the side, and let's go on from there. Why couldn't it get to the side. What's keeping it from getting to the side?

T: The sides of the pot.

Int: Ah. OK. The side of the pot. What about when it gets above the sides of the pot, now, and is out there. Why doesn't it, maybe, go up a little and ssssp? [The interviewer indicates steam falling downward.] You know, fall down.

T: Um. Well, it's heat and heat rises.

Int: OK. "Heat rises." OK. Now, I'm just trying to help you to figure out which one of these you like. Umm. Why does heat rise?

T: Hm. I don't know. It's cold is near the--um--ground, and heat's ... [The student pauses.]

Int: OK. Cold air is at the ground and heat is ... ?

T: Up.

Int: OK. "Up?" Uh. Have we figured out which one of these we like yet, or not?

T: I'd say "A."

Int: OK. "The droplets are composed of material which rises naturally." OK. Um. In "B," ...

T: Not really.

Int: You're still not sure? Well, let's--let's keep going on our--on our "cold is down and heat is up" thing. OK? Um. If cold is down and heat is up, then that would cause anything that's what to down and anything that's what to go up? Let's go like one more step.

T: Anything that's cold goes down and anything thast's hot goes up.

Int: OK. Now look back at the steam. Why did it go up?

T: Because it's hot.

Int: "Because it's hot." OK. So you really ... Well, we can--we don't have to take an "A" or "," if you really don't feel like it. Let's look at each one and see if you understood it or not. Tell me what "A" is trying to say. "The droplets are composed of material which rises naturally." OK. Do you understand all those words?

T: Uhuh. [Yes.]

Int: There is no word that skipped by you, or something like that. OK. Um. What's it ... Just in your own words, now. [The interviewer indicates answer "A."] What did that one tell you?

T: Um. That something inside 'em is making it go up.

Int: OK. Now, let's look at "B." "The upward pushes on each droplet overcome the downward pushes and pulls." Is there any word in there that you don't really know?

T: Huhuh. [No.]

Int: Anything that is tricky? OK. Do you know what "overcome" means?

T: Uhuh. [Yes.]

Int: What does it mean?

T: It means overpower, like.

Int: OK. Um. What is that trying to say, in your own words? [The interviewer indicates answer "B."]

T: OK. Some force that makes it go up, and overcomes the force that's making it stay down in the pot.

Int: OK. What force is trying to make it go up? As a guess.

T: I don't know.

Int: What force is trying to make the steam go down?

T: Gravity.

Int: OK. Let's stop on this question, and ... You helped a lot. And we're just going to go on to the next one. Um. Even without looking at the words, can you see what's happening here? [The interviewer indicates the Spoon Falling picture.]

T: Looks like something fell off the stove.

Int: OK. I didn't know how to draw this. [The interviewer laughs.] This thing is supposed to be a big spoon. They call it a ladle.

T: A ladle.

Int: Looks better on the computer. I--I'm not the greatest artist in the world, you'll notice occasionally here. OK. And so you recognize that's the stove. Right? And there's our old friend the pot. OK. Now here's the question. Read that and ... [The interviewer indicates the Spoon Falling question, with the picture and question.]

T: Why does the steel spoon fall instead of rise?

Int: OK. Now. Is there any word in there that--that fools you or you don't understand?

T: Huhuh. [No.]

Int: OK. Now. What would you answer?

T: Gravity.

Int: OK. Can you say more than just "gravity?" What about gravity? What's gravity doing?

T: Well it ... It makes things go down, instead of just float around the air.

Int: OK. Why do we have gravity?

T: Um. So things wouldn't be in chaos and everything.

Int: OK.

T: And the ...

Int: Go ahead. "Chaos" is one of my favorite words. [The interviewer laughs,] It is. Um. If we didn't have gravity, would the spoon rise?

T: Probably. Yeah.

Int: OK. "Probably." Um. Now, let's look at the thing that has the answers on it. We'll play our--our fun old answer game. OK. First, just look at "A." Read "A."

T: Steel is a material which moves downward naturally.

Int: OK. And "B."

T: Gravity pulls the spoon downward.

Int: OK. Now, did you understand what both of those meant?

T: Uhuh. [Yes.]

Int: If you had to choose "A" or "B," what would you have chosen?

T: "B."

Int: OK. What makes you feel that "B" is better?

T: Ummm.

Int: What's wrong with "A?" Let's do it that way. Or, bothers you a little about "A?"

T: Well, I don't know. I just think "B" is better.

Int: OK. What's better about "B?" What's the extra thing that's in "B" that's not in "A," let's say?

T: The gravity part of it.

Int: "The gravity part of it." OK. Because there is no mention of gravity in part "A?"

T: Uhuh. [Yes]

Int: OK. Ummm. Let's go on to the next one. I'm happy with that. Here we go. [The interviewer indicates the Softball-Cinderblock Falling picture.] What does that look like, and what does that look like? [The interviewer indicates the two objects.]

T: A brick and a baseball.

Int: OK. Now, read the thing.

T: A softball and a cinderblock are held the same height above the ground, and dropped at the same time.

Int: OK. You understand what I'm talking about? There's nothing tricky in that?

T: Uhuh. [Yes.]

Int: OK. Forget the answers for a minute. What happens when you do that? I hold them right straight with each other, right? [The interviewer pretends to hold both objects above the ground.]

T: Uhuh. [Yes.]

Int: And I drop them at the same time. You tell me what's going to happen, in your own words?

T: Well, they'll--um--both go down and hit the ground.

Int: OK. "Both go down and hit the ground." Um. What happens as they're falling? To their speeds?

T: Um. The velocity--it gets more.

Int: Ahah. Until?

T: Until it reaches its terminal velocity, and until it hits--hits the ground.

Int: OK. What makes it speed up? What makes the velocity increase?

T: Well, the more weight it picks ... I don't know.

Int: Wait. Wait. Wait. Let's just talk about one ... Look at the softball. It could be a baseball, too. I'm holding the softball here. [The interviewer pretends to hold the softball above the ground.] OK? Now what did you mean by "more weight?"

T: Well ... Forget that. I don't know.

Int: Forget it? OK. I release it. Now what happens?

T: It goes down.

Int: OK. "It goes down," and that's because of?

T: Gravity.

Int: OK. Let's look at the answers part. Um. Let's just read the first question. OK? Read it.

T: OK. With no air resistance, which object will strike the ground first? Softball. Cinderblock. They hit at same time.

Int: OK. Did you understand the question?

T: Uhuh. [Yes.]

Int: OK. Good. Um. Did that word "resistance" bother you?

T: No.

Int: What does "resistance" mean?

T: Resistance--that it's keeping it from coming.

Int: OK. So--um--so when I say there is no air resistance, then I mean what?

T: The air is not trying to keep it from going down.

Int: OK. So what--what would you put for that? "A," "B," or "C?"

T: Um. I say "B."

Int: OK. "Cinderblock." Now, let's look at the second question and do the same thing. [The interviewer indicates the second question for the Softball-Cinderblock Falling question.]

T: With no air resistance, which object will be moving faster when it strikes the ground? Softball. Cinderblock. They hit at same speed.

Int: OK. You want to take a guess? I mean ... In Tom's mind, what?

T: Ummm. Cinderblock.

Int: OK. "Cinderblock." OK. So you put "cinderblock" for both of those, which makes sense. OK. Now, why did you think that the cinderblock will hit the ground first, over the softball?

T: It will be heavier.

Int: OK. "It will be heavier."

T: More mass.

Int: More what?

T: Mass.

Int: OK. "More mass." That's nice. Um. And just to go through our thing ... Because a thing has more mass, why does that mean it--it hits the ground first?

T: Well, it's heavier and it's going down.

Int: Why is it going down?

T: Gravity ...

Int: OK.

T: ... makes it pulling down and it's going down faster than the ball.

Int: OK. So, in other words, when gravity ... But when something has more mass, gravity affects it in what way? If this guy has more mass than this guy, how does gravity affect the more massive one? [The interviewer pretends to hold up two objects above the ground.]

T: It makes it fall faster.

Int: OK. Excellent. Let's go on, onward and upward, to the next question. Here we go. [The interviewer indicates the Bicycle Slowing picture.] We have here. OK. Just stare at it. Forget the knobby tires.

T: Uhuh. [Yes.]

Int: That happened when I transferred it from a different program. They got bumpy for some reason. Um. Does that bother you--that nobody is sitting on the bicycle? Yes or no?

T: Huhuh. [No.]

Int: It doesn't? Bicycles can--can move along, a little bit at least, without somebody sitting?

T: Well, no. They can't.

Int: No. "They can't." OK. Well, let's read the question. Go ahead and read that.

T: The rider has stopped pedalling the bicycle. The moving bicycle is slowing down. Why is the bicycle stopping?

Int: OK. Now, I--I've kind of told you a little story there to get it in your mind. Right? What do you picture when you read that? What--what's happening in this thing?

T: Well, the rider's pedalling the bicycle. Then he gets off, and the bike's still going.

Int: Uhuh. [Yes.]

T: But it's not going as fast.

Int: OK.

T: It's slowing down.

Int: And now, before we show the answers, why do you think it's slowing down?

T: Because somebody is not moving the wheels to make it go forward.

Int: OK. "Somebody is not moving the wheels to make it go forward." Um. And is anything trying to slow it down? Somebody is not pushing it forward, but is anything trying to slow it down?

T: Friction.

T: "Friction?" What's friction? [The student rubs his hands together.]

Int: OK. And why are you holding your hands and doing like that? [The interviewer laughs.]

T: That's friction.

Int: You're trying to tell me that's friction?

T: Yeah.

Int: OK. When the bicycle is rolling along the ground, where is this friction taking place?

T: It's against the pavement or whatever he's driving on, and the wheels ... are ... going ...

Int: OK. "Against the pavement and the wheels." And you're saying ... So you're saying friction is trying to slow it down. Let's look at the answers and see what we're going to ask you. [The interviewer indicates the 'Bicycle Slowing question.] Please read the "A" answer.

T: There is a friction force acting on the bicycle.

Int: OK. And ... "B."

T: No force acts on the bicycle, and all objects will stop when no force acts on them.

Int: OK: Did you understand both of those answers?

T: Uhuh. [Yes.]

Int: OK. What do you think? "A" or "B?"

T: Um. I think both.

Int: [The interviewer mis-hears Tom, and thinks that he said that he would pick answer "B."] OK. "No force acts on the bicycle and all objects will stop when no force acts on them." OK. What's a little wrong about "A?" Why did you pick "B" over "A?" What--what bothers you about "A?"

T: Ummm.

Int: Or what is better about "B?" You can tell me either way.

T: I think both of 'em.

Int: You like them equally?

T: Uhuh. [Yes.]

Int: OK. So you don't really want to say "B" now?

T: It's both of 'em, I think.

Int: They're about equally--equally true, huh?

T: Uhuh. [Yes.]

Int: Um. In "A," "There is a friction force acting on the bicycle." You agreed with that?

T: Uhuh. [Yes.]

Int: From what we said before? OK. Uh. So in "B," "No force acts on the bicycle." You agreed with that?

T: Uhuh. [Yes.] 'Cause the person jumped off.

Int: OK. "'Cause the person jumped off."

T: He's not pedalling.

Int: And--and how about this right here, "All objects will stop when no force acts on them." Right? That makes sense?

T: Uhuh. [Yes.]

Int: OK. If you disagree, tell me. Because I want to know.

T: No.

Int: You sure? OK.

T: [The student starts to say something.]

Int: I am willing to hear anything.

T: No.

Int: And when I transcribe it, I won't put your name there. I'll just put "T."

T: Yeah.

Int: You can tell me wild and woolly stories. OK. We're--we have two to go. OK. Here's the picture. [The interviewer indicates the Can-Anvil Falling picture.] Uh. What do those two things look like to you?

T: An anvil and some kind of cylinder--can, or something.

Int: "An anvil and a cylinder or can." And it looks like they're doing what?

T: Falling.

Int: OK. And, uh. This probably reminds you of one of the other questions. Right?

T: Yeah.

Int: If we--we hold them up here and we release them ... We've said this before. They're going to do what?

T: Fall.

Int: And that's because ... Why?

T: Gravity.

Int: Uhuh. What does gravity always do? Or ...

T: It makes things go down.

Int: OK. Let's look at the answers. No, just the question. [The interviewer indicates the Can-Anvil Falling question.] Please read that. Let's see ...

T: An iron anvil and an aluminum can are held the same height above the floor and dropped at the same time.

Int: OK. Why do you think they said "the same height?" Would it be different if they were dropped at different heights?

T: Uhuh. [Yes.]

Int: What would be different?

T: 'Cause one would be going up in the air ...

Int: Uhuh.

T: ... and farther up in the air, and one would be closer to the ground. It'd take less time for the one closer to the ground to get to the ground.

Int: Ahah. OK. Now, what do you think I'm going to ask? [The interviewer laughs.]

T: Which one will get there first.

Int: Let's see what I ask. Oops. Must be over here. Da da da da. OK. Please read the first question. [The interviewer indicates the first question for the Can-Anvil Falling picture.]

T: With no air resistance, which object will gain speed faster? Anvil.. Aluminum can. They gain speed equally.

Int: OK. And you already told me about what "no air resistance" means. So, I assume that you can understand this?

T: Uhuh. [Yes.]

Int: What does "gain" mean? You don't know? You know what "gain" means? What does that mean?

T: Just--uh--get. Uh ...

Int: OK. So that means if--"if no air resistance, which object will get speed faster." OK. What will you put?

T: Um ... [Long pause.] Hmmm ... [Long pause.] I'd say they gain speed equally.

Int: OK. Um. There's a word that sometimes people use. It's a real big, showy word--to mean "gain speed." Have you ever heard of that I'm not going to use it in the question, but ... There's a word that means "gain speed"--like if your car "gains speed," you know. Jump in there and floor it. Nymmmmm! [The interviewer imitates the sound of a car speeding up.] Have you ever heard of it?

T: [Long pause by the student.]

Int: It's one word that means "gain speed" or "get speed." You know, "increase speed." I'm just curious. Because I don't want to use it. I think it would be ... not an eighth-grade word. Good. You don't know it. Um.

T: Well, I might know it if you tell it. But I don't know. I don't think.

Int: OK. I want to ask another question. You see these--these lines here? [The interviewer indicates the "speed lines" above the falling can and falling anvil.]

T: Uhuh. [Yes.]

Int: You understand what I mean by putting those lines there?

T: Uhuh. [Yes.]

Int: What do I mean?

T: It's their falling and ...

Int: OK. It's just to--to tell the person that they're ...

T: Falling.

Int: OK. They're falling. Great. That's good. Um. Please read that. [The interviewer indicates the second question for the Can-Anvil Falling picture.]

T: The anvil falls, rather than rises, because ... Iron is a material which moozes--moves downward naturally ... Its weight pulls it downward."

Int: OK. Is there a difference between "A" and "B?"

T: Well, a little bit. It says ... "A"--it makes it sound like the iron itself--it'll go upward, instead of downward ...

Int: Uhuh. [Yes.]

T: ... because it rises, iron rises. And "B"--it makes it think like ... it goes like all objects go downward.

Int: And so "B" is a little more than "A" in what ... ? What's in "B" that's not in "A?"

T: [Long pause by the student.]

Int: That all objects go down, or ... ?

T: That ...

Int: Go ahead. I'm sorry.

T: Weight ... Or something.

Int: OK. "Weight or something." Um. Pick one. Which do you think is the right answer, or the most right answer?

T: "B."

Int: "B." OK. Um. "Its weight pulls it downward." Uh. What does "weight" mean? Just to make sure?

T: It's the force of gravity--gravity on an object.

Int: OK. So weight is the "force of gravity on an object." And "its weight pulls it downward." So, in other words, to say it in different words than that. If you didn't even have to see this, what would--how could you say that in different words than "its weight pulls it downward?" [The interviewer covers the "B" answer.]

T: It's ... um.

Int: From stuff you just said, maybe.

T: Well, the gravity pulls it downward.

Int: OK. Um. Let us pass on to the very last question. You're doing great. You read well. I'll bet you do well in school. True or False?

T: True.

Int: OK. Um. Here we go. I'm not going to show you the question for a minute. [The interviewer indicates the Cup Sliding picture.] Uh. What do you see there happening?

T: Looks like a string tied to a cup ...

Int: Uhuh. [Yes.]

T: ... to the handle. And somebody's pulling the string. And the cup's moving across the table.

Int: Ahah. OK. Let's look at the question. Please read that.

T: A cup is being pulled across a tabletop with a string. If the cup keeps moving at the same speed, it is because "

Int: OK. Now, so you understand the situation?

T: Uhuh. [Yes.]

Int: OK. What does that mean, "at the same speed?"

T: It's not going faster, or it's not slowing down.

Int: Ahah. OK. Good. Ready for the answers?

T: Uhuh. [Yes.]

Int: Let's look at only the "A" answer for a minute. [The interviewer indicates the "A" answer to the Cup Sliding question.] Please read the "A" answer.

T: The steady pull with the string is not balanced by another force.

Int: OK. Now. There is a couple of words there I--I want to ask about, just to know if they're fooling you or not. You know what "steady" means?

T: Uhuh. [Yes.]

Int: What's it mean? Like, "steady pull" means what?

T: Well, it's going at the same rate. It's not jerking it, or anything, to make it go faster at the end.

Int: OK. And--and "balanced." What does "balanced" mean?

T: It's equal on both sides.

Int: OK. So let's read that again. "The steady pull with the string is not balanced by another force." OK. What does that mean? In your own words. Talking about this thing then. [The interviewer indicates the Cup Sliding question.]

T: OK. When somebody pulls the string, it's not equalled by another force.

Int: OK. Let's read "B." OK. Please read "B." [The interviewer indicates answer "B" for the Cup Sliding question.]

T: The steady pull with the string is balanced by the force of friction between the cup and the tabletop.

Int: OK. What's in "B" or in "A" that"s not in the other one?

T: OK. In "B," it has--it says--um--the force of friction is acting on it. In "A," it says there's no force acting on it.

<u>Int</u>: OK. What do you like, "A" or "B?"

<u>T</u>: [The student pauses.] Umm. "B."

<u>Int</u>: OK. "The steady pull with the string is balanced by the force of friction between the cup and the tabletop." Why do you not like "A" so much? What's missing from "A" that you think is better in "B?"

<u>T</u>: But it don't talk about friction in there [in "A"]. And if you just pulled it a bit and stopped, the cup would just slide across.

<u>Int</u>: Ahah: If there was ...

<u>T</u>: No friction.

<u>Int</u>: Ahah. So, in other words, friction would do what to the cup?

<u>T</u>: Um. If the person keeps pulling it, it would make it go at the same speed.

<u>Int</u>: OK. What if the person pulled it a little, and let go?

<u>T</u>: It would slow down.

<u>Int</u>: OK. Because of?

<u>T</u>: Friction.

<u>Int</u>: OK. I'll bet you're a good science student. And you have sure helped me. OK? Thank you very much.

<u>T</u>: Uhuh. [Yes.]

<u>Int</u>: Now. Let me turn this ...

VITA

HERMAN G. WELLER

Herman G. Weller

Office
College of Education
Division of Curriculum and Instruction
300 War Memorial Hall
VPI & SU
Blacksburg, Virginia, 24061-0313
(703) 231-5587

Home
6000-J, Terrace View Apts.
Blacksburg, Virginia, 24060
(703) 951-8478

PROFESSIONAL OBJECTIVE

University faculty position in science education, instructional systems design, and/or educational computing.

ACADEMIC TRAINING

Degree	Major	University	From yr. to yr.
Ed.D.	Curriculum & Instruction (Educational computing)	Virginia Polytechnic Institute and State University	1986 - 1990
-----	Computer Education (13 courses, 34 qtr. credits)	University of Oregon	Summers, 1984 - 1986
M.S.	Biophysics	Michigan State University	1971 - 1974
M.A.T.	Physics	Michigan State University	1969 - 1971
B.S.	Physical Science	Stanford University	1963 - 1966
-----	-----	University of Denver	1960 - 1962

PROFESSIONAL EXPERIENCE

Position	Institution	From yr. to yr.
Cunningham Dissertation Fellow Completion of dissertation.	Virginia Polytechnic Institute and State University	Aug. 1989 - present

PROFESSIONAL EXPERIENCE (continued)

Position	Institution	From yr. to yr.
Database Research Consultant Construction, programming, and supervision of input to databases for analyses of National Survey of [742] Professors of Vocational Teacher Education and [78] Institutional Questionnaires.	National Center for Research in Vocational Education VPI & SU Office	July 1989 - present
Computer Laboratory Assistant Summer Program for Excellence in Physics and Physical ScienceTeaching College of Education, C & I	Virginia Polytechnic Institute and State University	June - Aug. 1987
Graduate Assistant College of Education Education Microcomputer Lab.	Virginia Polytechnic Institute and State University	Sept. 1986 - June 1989
Computer Coordinator/Teacher Supervision of 2 computer labs (30 microcomputers). Teacher of 8th-grade BASIC programming, 11/12th-grade Pascal programming. Teacher of honors physics, physics	Colegio Internacional de Caracas, Caracas, Venezuela (Accredited by Southern States Association.)	Sept. 1985 - June 1986
Teacher All 8 - 12 th science, math, and computer science courses except biology and algebra II.	American Cooperative School Monrovia, Liberia (Accredited by Middle States Association.)	1976 - 1985
Science Dept. Chairman	American Cooperative School Monrovia, Liberia	(1984 - 1985)
Computer Coordinator Supervised the design, construction of Computer Room (13 carrels, 11 microcomputers). Supervised scheduling of H.S. classes into Computer Room for use of MECC software. Wrote scope-and-sequence for K-12 CAI use. Conducted Inservice Workshops for teachers (K-12) on use of computers and Computer Room.	American Cooperative School Monrovia, Liberia	(1983)
Science-math Dept. Coordinator	American Cooperative School Monrovia, Liberia	(1977 - 1979)
Graduate Assistant and Research Assistant	Michigan State University Biophysics Department	1971 - 1976

PROFESSIONAL EXPERIENCE (continued)

Position	Institution	From yr. to yr.
Teaching Assistant Physical Science 203 course. Rewrote and redesigned the course (See "Book" below).	Michigan State University Science & Mathematics Teaching Center	1970 - 1971
Teacher Geometry and general mathematics.	Philadelphia School Board Gratz High School	1968 - 1969
Peace Corps Volunteer/Teacher Physics, general science, math. Dormitory housemaster. Wrote physics scope-and-sequence for 3rd form-5th form (U.S. grades 10-12).	U.S. Peace Corps and Ghana Ministry of Education Bawku Secondary School Bawku, Ghana, West Africa	1966 - 1968

AWARDS AND GRANTS

Cunningham Dissertation Fellowship, 1989-90.
Full support for academic year. Highest competitive University award for doctoral students.

Instructional fee scholarship, Fall, 1988-89.
Tuition waiver for Fall semester.

Instructional fee scholarship, Fall, 1987-88.
Tuition waiver for Fall quarter.

Instructional fee scholarship, Fall, 1986-87.
Tuition waiver for Fall quarter.

PUBLICATIONS

Book

Detwiler, G. E., Foester, R. L., Grimes, M. W., & Weller, H. G., Jr. (1971). **Physical Science Laboratory Workbook**, Science and Mathematics Teaching Center, Michigan State University, 244 pages.

Refereed articles

Weller, H. G. (1985-86, December/January). ***Rocky's Boots*** **invades my course.** The Computing Teacher, 13(4), 41-43.

Weller, H., & Haug, A. (1977). **Effects of Ca^{2+} and K^{+} on the physical state of membrane lipids in *Thermoplasma acidophila*** . Journal of General Microbiology, 99, 379-382.

PUBLICATIONS (continued)

Weller, H. G., Jr., & Tien, H. T. (1973). **Determination of chlorophyll porphyrin ring orientation in black lipid membranes by photovoltage spectroscopy.** Biochimica et Biophysica Acta, 325, 433-440.

Article

Weller, H. G. (1988). **Interactivity in microcomputer-based Instruction: Its essential components and how it can be enhanced.** Educational Technology, 28(2), 23-27.
Reprinted in:
The Educational Technology Anthology Series, Vol. One, Interactive Video. (1989). Englewood Cliffs, N.J.: Educational Technology Publications (pp. 42-46).

Software review

Weller, H. G. (1984, November). ***Addition Magician*** . The Computing Teacher, 12(3), 42-43.

Readings/Proceedings

Ferro, S. & Weller, H. G. (October, 1988). **Effect of presentation rate on immediate recall of concrete nouns using imagery.** In R. A. Braden, D. G. Beauchamp, L. W. Miller, & D. M. Moore (Eds.), International Visual Literacy Association Conference Readings.

Ed.D. DISSERTATION

Microcomputer-Based Diagnosis and Remediation of Simple Aristotelian Alternative Conceptions of Force and Motion. College of Education, Virginia Polytechnic Institute and State University, Blacksburg, Virginia (1990).

M.S. THESIS

Determination of Porphyrin Ring Orientation in Spinach Chloroplast Extract Chlorophyll Black Lipid Membranes by Photovoltage Spectroscopy. Biophysics Department, Michigan State University, East Lansing, Michigan (1974).

PRESENTATIONS

Weller, H. G. (1990). **Development of Computer Software for Diagnosis and Remediation of Alternative Conceptions of Force and Motion: A Problem in Instructional Design as well as in Science Conceptual Change.** Annual Meeting of the Eastern Educational Research Association (EERA). Clearwater, Florida.

PRESENTATIONS (continued)

Weller, H. G. (1989). **Diagnosis and Remediation of Simple Aristotelian Alternative Conceptions of Force and Motion with a Computer Program.** Annual Meeting of the Eastern Educational Research Association (EERA). Savannah, Georgia.

Ferro, S., & Weller, H. G. (1989). **Effect of Imagery, Rate of Presentation, and Study Time on Recall of Concrete Nouns.** Annual Meeting of the Eastern Educational Research Association (EERA). Savannah, Georgia.

Ferro, S., & Weller, H. G. (1988). **Effect of Presentation Rate on Immediate Recall of Concrete Nouns Using Imagery**. Annual Conference of the International Visual Literacy Association (IVLA). Blacksburg, Virginia.

Weller, H. G. (1988). **The Components of Interactivity in Microcomputer-Based Instruction.** Annual Meeting of the Eastern Educational Research Association (EERA). Miami Beach, Florida.

Weller, H. G. (1984). **Computer Software Evaluation in Small Bytes.** Annual Meeting of the Association of International Schools in Africa (AISA). Lome, Togo.

Weller, H. G. (1983). **Integrating Computers into the Overseas School.** Annual Meeting of the Association of International Schools in Africa (AISA). Lome, Togo.

PROFESSIONAL WORKSHOPS

Weller, H. G., Born, H., & Thompson, L. (July 1988). **Patrick County Teachers Computer Inservice**. Two 3-hour workshops. VPI & SU Reynolds Homestead Learning Center. Critz, Virginia.

Weller, H. G. (June 1987). **Science Laboratory Computer Interfacing**. Patrick County Schools Administrative Workshop. One-hour session. Education Microcomputer Lab, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Weller, H. G., & McCallie, A. (September 1983). **Teacher Inservice Workshops in Microcomputer Use**. Two 3-hour workshops. Introduction of K-12 teachers to the school's new Computer Room, the use of its 11 microcomputers, and procedures for scheduling classes into the Room. American Cooperative School. Monrovia, Liberia.

TEACHER SUPERVISION

Internship (Spring 1988). One-term (Quarter) supervision of student teachers in secondary science. Head supervisor: Professor Thomas G. Teates (EDCI 7750). Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

COMPUTER CAMPS

Advanced Pascal teacher. (Summer 1989). Two-week Virginia Tech Computer Camp, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

COMPUTER CAMPS (continued)

Director/BASIC teacher. (Summer 1989). One-week VPI & SU Extension Computer Camp, Reynolds Homestead Learning Center. Critz, Virginia.

Advanced Pascal teacher. (Summer 1988). Two-week Virginia Tech Computer Camp, Virginia Polytechnic Institute and State University. Blacksburg, Virginia.

Pascal language aide. (Summer 1987). Two-weeks Virginia Tech Computer Camp, Virginia Polytechnic Institute and State University. Blacksburg, Virginia.

PROFESSIONAL SERVICE

Support person
Principals' Topical Seminar on the Special Education Process
Wytheville, Virginia (July 16, 1990)

Evaluation assistant
Conferences on evaluation of special education programs in Virginia school systems
Virginia Evaluation Technical Assistance Center (ETAC) Training
Richmond, Virginia (November 30-December 1, 1989; February 21-22, March 29-30, 1990).

Panel discussion chair
Conference honoring Promising Doctoral Research in Education, College of Education, Virginia Polytechnic Institute and State University, April 1989.

Judge
Roanoke City Science Fair, March 1990.

Judge
Roanoke City Science Fair, March 1989.

Session chair
Eastern Educational Research Association (EERA), February 1989.

Session chair
International Visual Literacy Association (EERA), October 1988.

Session chair
Eastern Educational Research Association (EERA), February 1988.

Accreditor
Member of Visiting Committee for a Middle States Association evaluation of the Hillcrest School, Jos, Nigeria (April 11 - 13, 1984).

PROFESSIONAL ORGANIZATIONS

- American Educational Research Association (AERA).
- Association for the Advancement of Computing in Education (AACE).

PROFESSIONAL ORGANIZATIONS (continued)

- Association for Educational Communications and Technology (AECT).
- Eastern Educational Research Association (EERA).
- International Society for Technology in Education (ISTE).
- International Visual Literacy Association (IVLA).
- National Association for Research in Science Teaching (NARST).
- National Science Teachers Association (NSTA).

LEVELS AT WHICH HAVE TAUGHT SCIENCE, MATH, COMPUTER SCIENCE, EDUCATIONAL COMPUTING

- Science, mathematics, computer science: 8 -12th grades.
- Physical Science: University undergraduate.
- Educational computing: University undergraduate and graduate.

UNIVERSITY TEACHING

Dodl, N., & Weller, H. G. (Spring, 1990). **Educational Applications of Microcomputers (EDCI 5314).** Graduate course co-taught in Curriculum and Instruction, College of Education, Virginia Polytechnic Institute and State University.

Dodl, N., & Weller, H. G. (Fall, 1987). **Microcomputers in the Classroom (EDCI 4980).** Undergraduate course co-taught in Curriculum and Instruction, College of Education, Virginia Polytechnic Institute and State University.

Weller, H. G. (1985). **Microcomputers in the Classroom (EDCI 531).** Graduate course taught as adjunct professor with the Department of Education at the University of South Carolina. Monrovia, Liberia.

Weller, H. G. (1969-71). **Physical Science 203 Laboratory section.** Undergraduate course for Elementary Education majors. Science and Mathematics Teaching Center. Michigan State University. East Lansing, Michigan.

RELATED CURRICULAR EXPERTISE

Computer languages

BASIC, GPSS/h (fair), Lisp (fair), Logo, Pascal, Prolog (fair).

Database programming

Have done *DBASE3+* (IBM XT) programming professionally.

Statistical analysis computer programming

General ability with SPSSX main-frame programming.

RELATED CURRICULAR EXPERTISE (continued)

Word processing languages

General ability with *MacWrite* (Apple Macintosh) and *FreeWriter* (Apple IIe/IIc). Have taught use of *AppleWorks* (Apple IIe/IIc), *Apple Writer* (Apple IIe), and *FrEdWriter* (Apple IIe/IIc).

Computer graphics applications

General ability with *MacPaint* (Apple Macintosh) and *MacDraw* (Apple Macintosh).

Computer interfacing with physical measurement devices

General ability with Vernier Company device interfacing with Apple IIe. Conceptual interfacing of various computers with physical measurement devices.

Spreadsheet, database

Have taught use of *AppleWorks* (Apple IIe/IIc) spreadsheet and database.

Desktop publishing

General ability with *Ready Set Go* (Apple Macintosh) desktop publishing software.

REFERENCES

Dr. Norman R. Dodl, Professor (Graduate Advisor)
Director, Education Microcomputer Lab.
Division of Curriculum and Instruction
College of Education
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0313 (703) 231-5587

Dr. John K. Burton, Professor
Division of Curriculum and Instruction
College of Education
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0313 (703) 231-5587

Dr. George E. Glasson, Assistant Professor
Division of Curriculum and Instruction
College of Education
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0313 (703) 231-5269

ADDITIONAL REFERENCES

Dr. D. Michael Moore, Professor
Division of Curriculum and Instruction
College of Education
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0313 (703) 231-5269

Dr. James W. Garrison, Associate Professor
Division of Curriculum and Instruction
College of Education
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0313 (703) 231-5598