THE DESIGN OF AN INSTRUCTIONAL MODEL TO TRANSFORM STUDENTS' ALTERNATE FRAMEWORK OF DYNAMICS

by

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B.Sc., The University of British Columbia, 1971

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

in

THE FACULTY OF GRADUATE STUDIES

(Department of Mathematics and Science Education)

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

August 1988

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Abstract

This study concerns the design and implementation of an instructional model that was intended to explicate students' alternate conceptions of dynamics and transform them into a conceptual set which more closely approximates Newtonian conceptions of dynamics. The design of this instructional model has employed Frame Theory as the basis for the development of an analytical clue structure that was used to describe students' alternate conceptions of dynamics and track any changes to these conceptions as the lesson sequence progressed. In addition, this instructional model has attempted to utilize discordant event demonstrations as the catalyst required to initiate transformations of the alternate conceptions of dynamics held by students.

Data for this study have been collected within an operational science classroom by video taping a series of lessons that dealt with the dynamics of linear acceleration and deceleration, and uniform motion. These data were subsequently reduced to lesson transcripts which were then analyzed, using the clue structure, for student conceptual data. These data were then reconstructed into conceptual frames that represented individual and collective student interpretations of force/motion events both before and after the demonstration of the discordant events. 'Before and after' comparisons were then made of these frames in order to determine if any conceptual transformation had occurred.

Results from this study have indicated that a majority of students that took an active role in these classes explained the motion of

objects, both before and after instruction, using a 'motion implies a force' set of conceptions. This study also found that the explication and representation of student conceptions of dynamics could be successfully accomplished by using the analytical clue structure to reconstruct transcript data into student interpretational frames of motion. Comparisons of the interpretational frames that students were employing before the demonstration of specific, discordant events with those frames that were being employed after these events indicated that use of discordant events to initiate conceptual transformation was only minimally successful.

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Acknowledgements

I would like to thank Dr. Gaalen L. Erickson of the Department of Mathematics and Science Education, the University of British Columbia, for his academic direction and support throughout all phases of the evolution of this thesis. I would also like to acknowledge the support provided to me by School District #24 (Kamloops) in the form of an educational sabbatical. Without this sabbatical this research would never have been started. Finally I would like to thank my wife and children without whose support and forbearance this research would never have been completed.

CHAPTER ONE

The Problem and Its Setting

The Statement of the Problem

A synthesis of previous research in students' beliefs of dynamics has delineated three, common viewpoints of force and motion. These are first, motion implies an application of force; second, force is associated only with motive objects; and third, external surface forces are the only types of forces available. This study postulates that these three common viewpoints, together, represent an alternate framework of dynamics. This study further postulates that this alternative framework is both pervasive and robust within student populations, and acts as an impediment to understanding Newtonian concepts of dynamics as presented in the classroom.

This study has undertaken, as its general problem, the design of an instructional model which can be used to explicate the alternate conceptions held by students and help students transform these to ones which more closely approximate a Newtonian framework of dynamics. In particular, this study has focussed upon that segment of the alternate framework that implies that all forms of motion require an application of force.

The Specific Problems

The general problem can be subdivided into three specific problems or objectives. These are:

1. to design an instructional strategy that will explicate the students' alternate framework of dynamics, and help them to transform

this alternate framework to a closer approximation of a Newtonian framework of dynamics.

2. to develop a theoretical perspective that will serve as the basis for an analytical clue structure (Roberts & Russell, 1975).

3. to collect qualitative date, within an operational classroom, that will allow inferences to be made concerning the influence of the instructional strategy on students' classroom concepts of dynamics on the basis of a clue structure analysis.

Each of these three issues, and their constituent problems, will be further amplified within Chapter Three - The Research Design.

Definitions

Alternate Framework

An alternate framework is a network of beliefs and conceptions concerning a class of things, situations, or events that has been constructed by an individual as a result of his or her experiences with specific members of the class. The elements of this network can include both intuitive and propositional knowledge.

Theoretical Perspective

Theoretical perspectives are "conceptualizations which provide ways of viewing the complexity of educational phenomena in orderly and meaningful patterns (Tyler, 1972)", as cited by Roberts & Russell (1975).

Clue Structure

A clue structure is defined as an analytical device used to ensure that the identified "theoretical perspectives are applicable to the phenomena being studied (Roberts & Russell, 1975, p. 115)."

Instructional Strategy

An instructional strategy consists of the design and implementation of the principal elements of instruction. These elements can include instructional objectives, content, mode of content presentation, and evaluation.

Instructional Model

An instructional model is an organization structure that relates the proportions and sequencing of the elements of the instructional strategy to those of the clue structure.

A Psychological Setting for the Problem

Characteristics of Students' Personally Constructed Beliefs

Almost without fail, all researchers who have investigated students' personal knowledge of dynamics attribute the presence of this knowledge to an attempt, by the individual involved, to construct meaning from their experiences with the motions of objects. This experiential base is assumed to be constructed from a combination of physical and linguistic experiences, and analogic reasoning.

Initially, due to a limited range of experiences, these meaning constructions might be represented as incoherent, "local theories" (Claxton, n.d., p. 8). However, as the experiential base broadens, Driver and Erickson (1983) suggest that these local theories can evolve into a "system of expectations" (p. 41) with predictive capabilities. Such a system will have strong idiosyncratic overtones and probably be continually reinforced because 'it works'. Additionally, elements of this personal expectation or belief system can be used as warrants or backing for warrants during the interpretation of novel, or new situations and events.

Although personally constructed beliefs are strongly idiosyncratic, many similarities among the expectations and beliefs of individuals have been recognized by researchers. This apparent anomaly arises from, at least, two possibilities. These are: first, that individuals will process information and construct meaning in similar ways, and second, that individuals are faced with a reasonably common set of experiential events from which to construct meaning. Thus, elements of personal knowledge, within specific contextual domains such as dynamics, can appear as universals.

How might such a system of idiosyncratically constructed beliefs and expectations of dynamics be represented? Initially, it is necessary to accept the previous assumption that individuals process information and construct meaning in similar ways. Once this assumption is accepted, one needs to locate a representation of individual information processing systems that could be generalizable across individuals. Such an information processing system is found in Minsky's (1975) frame theory.

Frame Theory and Personally Constructed Knowledge

Frame theory was developed by Minsky as a response to perceived problems with existing theories and models of human information processing techniques. For Minsky, these theories and models were "on the whole too minute, local, and unstructured to account - either practically or phenomenologically - for the effectiveness of common sense thought" (p. 211). In addressing these issues Minsky theorizes that:

> When one encounters a new situation (or makes a substantial change in one's views of the present problem) one selects from memory a substantial structure called a frame. This is a remembered framework to be adapted to fit reality by changing as necessary ... A frame is a data-structure for representing a stereotyped situation, like being in a certain kind of living room, or going to a child's birthday party (p. 212).

Thus, a frame "represents our inductive knowledge of the world as previous experience with that domain of objects" (Kuipers, 1975, p. 159) and, for the purposes of this research, will represent the fundamental unit of the theoretical perspective required to design the clue structure.

In the simplest sense, a frame represents a mental structure that contains either procedural data (derived from physical experience) or declarative data (derived from linguistic experience) associated with a unique event or situation. At this level, the data are idiosyncratic and the frame appears to closely approximate Claxton's concept of a local theory. These two types of frames can be integrated to form a more complex, but still idiosyncratic, frame if the individual perceives that they have originated from the same event.

Once established, an idiosyncratic frame provides a ready-made, heuristic strategy that can be applied to an analogous event. If the strategy is successful in providing a solution or explanation the frame will evolve in complexity. This complexity can be represented as an increase in the various levels within the frame.

The lower levels of the frame will contain the specific, idiosyncratic data from both events and are referred to as default values (Kuipers, 1975, p. 158). The default values from both events may or may not overlap in their entirety depending upon the degree of similarity between the events. They do, however, act as a set of data expectations or inferences that will appear the next time the heuristic strategy is used. In this regard, the default values appear to parallel the "system of expectations" mentioned by Driver and Erickson (1983).

The upper levels of the frame will contain stereotypical information about both events. As a result, these levels are fixed and probably represent a conceptualization of the events in question.

Further 'successful' applications of this dynamic structure to other contextually similar events result in an increase to the complexity of the frame. This increasing complexity can be represented as a continued expansion of the frame to include increasingly more generalized stereotypical knowledge and concepts associated within the context, and specific data (procedural or declarative) related to this knowledge. Within this representation the most general concept can be conceived as a superframe which subsumes the more specific frames. These specific frames, in turn, subsume even more specific frames. In this fashion a "generalization hierarchy" (Winograd, 1975, p. 196) of frames is constructed.

This conceptualization of personal, inductive, domain-related knowledge as a collection of mental frames arranged in a generalization hierarchy provides a theoretical perspective for the representation of personally constructed knowledge. This representation will be more fully discussed in Chapter Three.

Rationale for the Problem

Educational Significance of the Problem

Many teachers and researchers have recognized that large numbers of students hold views of force and motion that can best be described as pre-Galilean. It has been assumed (and is assumed for the purposes of this research) that these views represent an impediment to the acquisition of Newtonian concepts of dynamics. This stance is most strongly stated by Viennot (1979):

> The intuitive scheme is, thus, widespread and tenacious. It resists the teaching of concepts which conflict with it, and it reappears even in the expert when he or she lacks time to reflect. Such tenacity is probably connected with the self-consistency of the scheme ... a major teaching effort is needed which goes beyond the conventional teaching of the Newtonian scheme alone ... students should be helped to make explicit their own intuitive reasoning with all its consequences, and to compare this with what they are taught (p. 213).

This research has set itself the task of transforming the intuitive scheme (alternative framework) by developing an instructional model that does go beyond the teaching of the Newtonian scheme alone. By doing so, it was conjectured that a more complete understanding of Newtonian concepts of dynamics, by students, might be achieved.

The instructional strategy, although designed externally to the classroom, has been developed and assessed within an operational classroom. This form of practical evolution has attempted to ensure that the instructional strategy is responsive to the demands of classroom systems. This responsiveness, combined with the inherent flexibility of the model, should ensure that the instructional model can be adapted by teachers to meet their own unique sets of requirements.

This research represents an initial step in the movement of a well-documented body of research data from analysis to full-fledged implementation in the classroom. This initial step incorporates both a naturalistic, open form of inquiry and a theoretical device derived from information processing theory. As such, this research provides a double perspective for future research. First, the form of the inquiry will provide the basis for more systematic investigations of the instructional model's ability to resolve the apparent conflict between alternate frameworks and desired concepts taught in the classroom. Second, the use of frame theory as an analytical tool for deciphering classroom interactions should provide future researchers with an additional perspective for interpreting and assessing the efficacy of other instructional models.

In summary, this research can make significant contributions to the improvement of both educational practice and research. This research provides an instructional model that is designed to increase students' understanding of Newtonian dynamics, and, at the same time, remain responsive to the demands of the classroom and the practicing teacher. Additionally, this research provides a base for future systematic research concerning the efficacy of the instructional model, and the use of frame theory as an analytical perspective for interpreting classroom interactions and student knowledge structures.

Theoretical Considerations

This research deviates from the standard practice of constructing the instructional strategy, in totality, from previously defined educational theory. This deviation arises from two considerations.

First, to this point, the general area of research in which this study is located has been heavily involved with cataloguing the elements of students' personally constructed knowledge, within particular phenomenological contexts, and not in developing theory or utilizing theory to explain the results. As West, Pines, and Sutton (1982) have pointed out:

> We cannot just list those researchers who claim to be Ausubelians, for example, and by doing so, discriminate their research from those who claim to be Brunerians or Kellians (p. 11).

Second, the acts of learning and understanding by an individual, within a classroom environment, are "artifactual" (Gowin, 1982, p. 26) events unique to the individual. As a result, no single theory can adequately account for the multiplicity of learning modes present in the classroom. Manicas and Secord (1983) explicitly recognize this problem when they argue that:

> The point here is precisely that specific behaviors - like most events in the world - cannot be explained as the simple manifestation of some single law or principle ... Indeed, the acts of persons are open-systemic events in which a variety of systems and structures are involved, systems that are physical, biological, physiological, and ... sociological as well (p. 405).

Because of these considerations, the resulting instructional strategy cannot be considered to be immutable. Rather, the strategy is open to modification by the demands of the classroom environment. In this way the gulf between educational theory and practice might be bridged.

Limitations

This research is limited in two ways. First, it does not conform with the classical view of generalizability in which external validity is established through the random selection of a sample from a well-defined population. Rather, this research has opted for a "natural basis for generalization" (Stake, 1978, p. 5). Second, the problem of attempting to establish equivalence between the constructs of a frame as a mental knowledge structure, and the alternate framework is extremely difficult. As a result, the validity of using elements of frame theory as an analytic device is open to question. Neither of these limitations is, however, considered to be a critical design flaw.

The issue of generalizability arises from two considerations. First, because this research has attempted to develop an instructional model based on student beliefs and cognitive processing techniques, it has been crucial that these beliefs and techniques be explicitly and qualitatively described. As a result this research has been limited to a single, operational class in order to obtain the high quality, rich descriptions that have been necessary for the development and assessment of the instructional model. Secondly, as has already been mentioned, this research has been directed at developing a practical instructional model that could be adapted by practicing teachers to meet their own sets of requirements. This direction, however, requires that this research be placed within a classroom context that is both recognizable and empathetic to them, for as Lincoln and Guba (1985) have pointed out

> ...if you want people to understand better than they otherwise might, provide them information in the form in which they usually experience it. They will be able, both tacitly and propositionally, to derive naturalistic generalizations that will prove to be useful extensions of their understandings (p. 120).

The developmental nature of this research is also apparent in the attempt to develop an analytical device, the clue structure, from the constructs of frame theory and the students' alternate frameworks. At this stage, it is not clear whether or not alternate frameworks can be productively interpreted in terms of frames, as outlined by Minsky (1975). Certainly, there is a difference in the level of application of these constructs; that is, frames are considered to be idiosyncratic, whereas alternate frameworks are generalized representations of commonalities between idiosyncratic beliefs. The strength and prevalence of the commonalities that have led to the construction of the alternate framework, however, indicate that the individuals involved have constructed knowledge from experience in remarkably similar ways. This similarity of construction lends credence to the use of frames as a heuristic device for analytical purposes.

Because of its developmental character, this research can only be considered to be at a hypothesis generating stage. As a result, the issues of generalizability and validity will have to be addressed more systematically in subsequent studies.

CHAPTER TWO

A Review of the Related Literature

Over the past decade an increasing amount of science education research has been directed towards uncovering and cataloging students' beliefs concerning specific physical phenomena. It has been hoped that such research would eventually lead to an improvement in the quality of understanding of these phenomena by students in the sciences and technologies (Gilbert and Watts, 1983). To date, the research topics have been eclectic with probes being launched at areas such as force, uniform and accelerated motion, energy, electricity, heat, light, and the particulate nature of matter. Within these areas a substantial number of studies have targeted the associated areas of force and motion as being especially fruitful for the delineation of students' beliefs. The rationale for this choice has probably best been stated by Champagne, Klopfer, and Gunstone (1982, p. 399):

> The development of practical principles of motion is necessary for coping with the moving objects that are encountered in daily life. Thus, all students begin the formal study of mechanics with an experientially verified set of principles that allow them to predict the real world. In addition, the same words that are used to describe and explain motion in everyday language also are used by physicists.

Within the set of research studies that have investigated students' beliefs concerning force and motion, i.e. dynamics, two sub-sets of research categories have been recognized. These are: first, those studies that have catalogued student beliefs of dynamics on the basis of their own merits and "without assessment against any externally defined system" (Driver & Easley, 1978, p. 63), and second, those studies that have assessed student beliefs of dynamics relative to their congruence with accepted scientific concepts. These two categories are referred to, respectively, as the ideographic and the nomothetic (Driver & Easley, 1978). It is these two categories that shall be used as the basis for delineating research strands within the literature.

The Ideographic Approach

Aguirre (1978), Kuhn (1979), Trowbridge, Lawson and McDermott (1980), Watts (1983, 1982), and Watts and Zylbersztajn (1981) have all directed their research along ideographic strands. Their studies have investigated students' beliefs of forces in equilibrium, free-fall motion, dynamics, gravitational force, and force in general.

The terminologies used by these researchers to describe their analytical units reflect their ideographic approach. Aguirre (1978) and Kuhn (1979) both seek to describe student beliefs. Their proposition is that these beliefs are experientially based and, to a great degree, formed externally to formal instruction. Trowbridge, Lawson, and McDermott (1980a, b) seek to elicit the students' "naive conceptualizations" (p. 1) which they equate with primitive beliefs or preconceptions. Watts and Zylbersztajn consistently attempt to reconstruct a students' alternative framework which they define as a set of "coherent ideas of the world based on their own experiences" (p. 360). Clearly, these researchers have predicated their studies on strikingly similar assumptions. First, students are proprietors of idiosyncratic knowledge concerning scientific concepts. Second, this knowledge has been constructed on an experiential foundation. Finally, this knowledge has been acquired prior to formal instruction in the concept(s) in question.

These assumptions are reflected in the methodology and subjects utilized by the majority of these researchers. With the exception of the studies by Watts (1983, 1982), and Watts and Zylbersztajn (1981), all researchers have employed some form of clinical interview that would reflect the idiosyncratic nature of the knowledge being investigated. Watts and Zylbersztajn (1981) were interested in "assessing the popularity of some particular alternative frameworks" (p. 360) from a large sample of students and thus opted for a paper and pencil test. In addition, all researchers have used subjects who have had little or no exposure to formal physics instruction in order to investigate the experiential nature of this knowledge.

Results

Although a number of different contexts are employed in these investigations similarities in results do occur. All researchers found that the majority of their subjects believed that if an object is moving a force must be acting upon that object. The converse of this position was also held to be true. Variations of this position were recognized by Kuhn (1979) who found a number of his subjects equating constant speed with constant force, and by Aguirre (1978), Watts and Zylbersztajn (1981), and Trowbridge, Lawson and McDermott (1980) who all found that a majority of their subjects believed that motion due to the interaction of two bodies was due to the body with the greater force. Aguirre's (1978) results indicate that subjects below twelve years of age simplify this belief even further and recognize only one force in the system thus suggesting that this belief may be age dependent. Both studies by Watts (1982, 1983) and that by Watts and Zylbersztajn (1981) indicate that some children require that there be a medium, such as air, through which a force can act. In the case of the latter study this belief was specifically cited to support the subjects' contention that the moon lacked a gravitational field. These researchers also identified a belief among their subjects that an application of force always resulted in some form of action. The greater the application of force, the greater was the resultant activity. The belief that gravitational force increases with height was common to a substantial number of subjects in the studies of Aguirre (1978), Kuhn (1979), Watts (1982), and Watts and Zylbersztajn (1981). Aguirre, however, found this perception most prevalent in subjects less than eleven years of age suggesting that it may be age dependent.

Other beliefs were recognized in single studies. Watts (1983) reported the existence of the following beliefs: force is an obligation to complete an action against some form of resistance, objects that are restrained in position have an inherent force, objects that can or might cause events to occur have an inherent force, and moving objects have inherent force. Aguirre (1978) also reported the existence of a belief in the inherent force of restrained objects. In this case, the inherent force could only 'hold' and not 'pull'. Aguirre (1978) also recognized that a large number of his subjects could only identify a force equilibrium condition using a position criterion. Watts (1982) identified the belief that gravitational force only operates when objects fall.

Viewed in totality these beliefs and perceptions appear to represent a mixture of Aristotelian-like and Impetus theories of dynamics. The representative sample of subjects of these studies views force and motion from a pre-Newtonian position but, as Watts and Zylbersztajn (1981) noted at the beginning of their paper:

> It is no news that children have pronounced Aristotelian views about force and motion, and often reject, or fail to appreciate, the substance of Newton's version of mechanics (p. 360).

The Nomothetic Approach

The majority of studies investigating students' beliefs of force and motion have occurred along the nomothetic strand. Researchers operating from this perspective are Champagne, Klopfer, and Anderson (1979), Clement (1981, 1977), diSessa (1981), Fleshner (1970), Gunstone and White (1981), Helm (1978), Leith (1982), McCloskey (1983), McCloskey, Carmozza, and Green (1980), Minstrell (1981), Saltiel and Malgrange (1980), Sjoberg and Lie (1981), Trowbridge and McDermott (1980a, b), and Viennot (1979). These researchers have attempted to assess student beliefs relative to accepted scientific concepts within the following contexts: classical mechanics (Champagne, Klopfer, and Anderson, 1979, Sjoberg and Lie, 1981), computer-simulated motion in two dimensions (diSessa, 1981), force (Fleshner, 1970), gravitational force (Gunstone and White, 1981), dynamics (Helm, 1978), curvilinear and projectile motion (McCloskey, 1983 and McCloskey, Carmozza, and Green, 1980), the 'at rest' condition of an object (Minstrell, 1981), motion and velocity in varying frames of reference (Saltiel and Malgrange, 1980), velocity and acceleration (Trowbridge and McDermott, 1980a, b), and energy and motion (Viennot, 1970). The terminology, methodology, and subjects used in these studies all reflect the nomothetic perspective.

The terminologies used by these researchers to describe their analytical units have similar connotations. Champagne, Klopfer, and Anderson (1979), Clement (1981), Helm (1978), Leith (1982), McCloskey (1983), Sjoberg and Lie (1981), and Trowbridge and McDermott (1980a, b) all attempt to identify students' concepts and/or misconcepts. The implication is that these will not, in all probability, match the accepted scientific concept. DiSessa (1981) attempts to define students' "naive knowledge" (p. 1) that has yet to reach the sophisticated level of the expert. Similarly, McCloskey, Carmozza and Green (1980) try to describe student "naive beliefs" (p. 1139). Fleshner (1970) speaks of determining how "formerly acquired knowledge" (p. 201) is rationalized with newly acquired school knowledge. Gunstone and White (1981) wish to assess students' predictive and explanatory capabilities when faced with formal physics problems. Minstrell (1981) attempts to elicit student pre- or alternate conceptions prior to instruction in the accepted scientific concept. Viennot (1979) wishes to reconstruct student reasoning patterns in an attempt to determine how they interact with teaching. What seems to be implicit in these terminologies is that student beliefs are somehow at odds with accepted scientific thought.

In a similar fashion, the methodologies utilized reflect the nomothetic approach. In order to contrast student beliefs with scientific concepts the majority of researchers have employed paper and pencil tests with definable 'right' answers. Exceptions to this methodological format are found in the investigations of Clement (1977), diSessa (1981), Fleshner (1970), McCloskey (1983), Minstrell (1981), and Trowbridge and McDermott (1980a, b). All of these researchers, with the exception of Minstrell, have used some form of clinical interview in order to observe their subjects in physical situations. Minstrell's research occurs with a classroom setting, where the researcher is the teacher, and thus, he has opted for a whole class discussion/interview format.

The subjects investigated, with the exception of one study, have been exposed to some type of formal physics instruction. The use of these subjects has allowed the explicit juxtaposition of the students' beliefs of dynamics with the Newtonian concepts of dynamics. The exception to the use of the subject group has occurred in the study by Leith (1982). In this instance the researcher was attempting to validate a set of tasks derived from a Piagetian study and used a group of school children, 7-12 years of age.

In general, researchers investigating students' beliefs of dynamics from a nomothetic perspective will use 'right answer' oriented paper and pencil tests given to students that have been exposed to some level of formal instructions.

Results

The results from those studies employing the nomothetic approach have, for the most part, been deduced from error analyses of student responses to questions (either written or verbal) concerning Newtonian mechanics. These results will be discussed under two categories: first, those that deal with concepts of dynamics, and second, those that deal with kinematics.

A belief that appears to be pervasive among subjects studied by a large number of researchers (Champagne, Klopfer and Anderson, 1979, Gunstone and White, 1981, Minstrell, 1981, Saltiel and Malgrange, 1980, and Viennot, 1979) is that a body at rest is devoid of any applied forces. The converse of this belief has also appeared frequently and in a number of forms. Champagne, Klopfer and Anderson (1979), and Minstrell (1981) report that a number of their subjects held the belief than any application of force will produce motion and that a constant application of force will produce uniform motion (Champagne, Klopfer and Anderson, 1979). Allied with this belief are the beliefs that velocity is proportional to the applied force (Champagne, Klopfer and Anderson, 1979) and that a change in applied force results in acceleration (Champagne, Klopfer and Anderson, 1979, Clement, 1981, Leith, 1982). Clement (1981), diSessa (1981), McCloskey (1983), Carmozza and Green (1980), Sjoberg and Lie (1981), and Viennot (1979) also identified subjects who believed that when two or more forces are present any resultant motion will be in the direction of the largest force. All of these beliefs contribute to a structure that Clement (1981) calls the "motion implies a force misconception" (p. 67). This structure, as McCloskey (1983) has pointed out, is reminiscent of the pre-Galilean Impetus Theory.

Related to this structure is the lack of consideration given by some subjects to frames of reference (McCloskey, 1983, Saltiel and Malgrange, 1980) and action/reaction combinations (Sjoberg and Lie, 1981, Viennot, 1979). Further removed, but still related to this structure, is the belief that applied force occurs as only a push or pull (Fleshner, 1970) which might lead to the belief, reported by Minstrell (1981) that only animate objects can apply a force.

Specific beliefs concerning motion due to gravitational force have been identified. Gunstone and White (1981) reported that a minority of subjects thought that gravitational acceleration was a function of an object's weight and weight was a function of the object's height above a reference surface. Sjoberg and Lie (1981) reported that approximately 15% of their subjects thought that a gravitational field requires some form of medium for it to be effective.

Observations concerning subjects' beliefs of kinematics have been made by Leith (1982), and Trowbridge and McDermott (1980a). All of these researchers found that their subjects tended to compare the speed/velocity of two objects on the basis of position (when two objects are side-by-side they have the same speed) or distance travelled (the greater the distance, the greater the speed). Leith (1982) also found that absolute speed of an object was equated with least travel time without regard to distance travelled. Trowbridge and McDermott (1980a, b) observed that a substantial minority (up to 30%) of their subjects judged relative acceleration on the basis of position, i.e. if one object passed another it had greater acceleration.

The results of the investigations concerning students' beliefs of mechanics that have taken the nomothetic approach are probably best summed up by McCloskey (1983), and Sjoberg and Lie (1981). First, McCloskey:

> Indeed, the ideas about motion held by most people with no formal training in physics, and by many who have completed at least one physics course, are much closer to the account given by the Impetus Theory than they are to Newtonian mechanics (p. 125) ... The striking similarity between the views of the medieval philosophers and those of our subjects suggests that the Impetus Theory is a natural outcome of experience with terrestrial motion (p. 127).

Finally, Sjoberg and Lie:

> This rather depressing picture "forces" (!) on us an understanding that the foundation of classical mechanics is far from self-evident, which many textbooks more or less assume. On the contrary, Newton's laws are contrary to common sense ideas developed intuitively and spontaneously by pupils (and adults) (p. 18).

A Comparison of Results

A comparison of the results of each research strand reveals a substantial level of congruence between both strands. This congruence was evident in subjects' beliefs concerning the effects of forces, possible sources of force, and the types of forces.

The most commonly elicited belief from subjects in both research strands was that motion is the result of a continuous application of force. This belief, or its converse, was recognized by all researchers operating along the ideographic strand and by Champagne, Klopfer and Anderson (1979), Clement (1981), Gunstone and white (1981), McCloskey (1983), McCloskey, Carmozza, and Green (1980), Minstrell (1981), Saltiel and Malgrange (1980), Sjoberg and Lie (1981), and Viennot (1979) from the nomothetic group. This belief reappeared, thinly disguised, in the belief that an application of constant force produced uniform motion (Kuhn, 1978, Champagne, Klopfer and Anderson, 1979), or as the belief that an application of a variable force results in acceleration (Watts and zylbersztajn, 1981, Champagne, Klopfer, and Anderson, 1979, Clement, 1981, Leith, 1982). Again, the strand boundaries appear invisible to these beliefs.

Descriptive statistics reported in studies from both strands suggest that this class of beliefs may be prevalent at many educational levels. Clement (1981) reported that 88% of the first year and approximately 70% of the second, third, and fourth year engineering students tested at an American university found it difficult "to think about an object continuing to move in one direction with the total net force acting in a different direction" (p. 67). McCloskey (1983) found that more than 33% of the American high school and college students he investigated explained motion in terms of an Impetus Theory. Approximately one-third of the Norwegian high school and college students utilized by Sjoberg and Lie (1981) consistently drew force arrows in the direction of motion of a pendulum bob. Watts and Zylbersztajn (1981) reported that 85% of the British, fourteen year old subjects they tested associated force with motion. Results such as these tend to suggest that the belief that motion implies a force is not only common but pervasive.

Subjects' beliefs concerning the interactive effects of simultaneous forces were also found to correspond closely. Using the ideographic approach Aguirre (1978), Trowbridge, Lawson, and McDermott (1980), Watts and Zylbersztajn (1981) reported that their subjects attributed any resultant motion only to the largest force. Similarly, diSessa (1981), McCloskey (1983), McCloskey, Carmozza, and Green (1980), Sjoberg and Lie (1981), and Viennot (1979), using the nomothetic approach, reported that their subjects believed than any resultant motion would be in the direction of the largest force. Directly associated with these beliefs is the failure of subjects to consider action/reaction combinations (Sjoberg and Lie, 1981, Viennot, 1979).

Subjects from both strands attributed force to only those objects that had motive characteristics. Within the ideographic strand Watts (1983) and Aguirre (1978) found that subjects attributed an inherent force to those objects that can or might cause events to occur. Minstrell (1981), operating from a nomothetic position, found that his students believed that only animate objects can apply a force. These beliefs strongly reflect the prevailing belief, discussed previously, that motion implies force.

External body forces, such as gravity, are not recognized by some subjects investigated under either research approach. Studies by Watts (1983, 1982), Watts and Zylbersztajn (1981), and Sjoberg and Lie (1981) found that subjects required gravity to act through some form of connecting medium. As a result gravity is transformed into an external surface force which pulls. Similar results were found in a study by

Fleshner (1970). He reported that his subjects believed that force could only be applied by a indirect push or pull. These reported beliefs suggest that only external surface forces (pushes or pulls) are recognized.

These congruent, or closely associated results suggest that the subjects involved in these studies view the effects, sources, and types of forces from a reasonably common position. Clement (1981) suggests that this viewpoint is a result of a common, experiential interpretation of force:

> In the real world, where friction is present, one must push an object to keep it moving. Since friction is often not recognized as a force by the beginner, the student may believe that continuing motion implies the presence of a continuing force in the same direction, as a necessary cause of the motion (p. 66).

If this common viewpoint is valid, it appears to represent an alternate framework of dynamics constructed from three basic tenets: first, motion implies an application of force, second, force is associated only with motive objects, and third, external surface forces are the only types of forces available.

In order to explicate and transform (where desireable and possible) the alternate framework of dynamics this research has adopted characteristics from both of the previous research strands. It assumes, as does the ideographic strand, that the presence of an alternate framework of dynamics is the result of an active construction, on the part of an individual, to explain personal movement and the motion of objects. Further, this research assumes, as does the nomothetic strand, that this alternate framework will be, to some degree, at odds with accepted scientific explanations of motion.

Methodologically, however, this research has diverged from these two strands. In order to explicate the alternate framework of dynamics that individuals have constructed this research has utilized a clue structure analysis of classroom discussions and debates (concerning the motion of objects) rather than clinical interviews or 'paper and pencil' tests. Additionally, this clue structure has been incorporated into an instructional model that has attempted to transform the alternate framework of dynamics to one that more closely approximates the Newtonian framework of dynamics. The design of this instructional model and its implementation within an operational classroom are the subject of Chapter Three - The Research Design.

CHAPTER THREE

The Research Design

The design base for this study is derived from a set of procedures described, initially in the Russian literature, as a teaching experiment (Kalmykova, 1966). More specifically, this study has used perspectives from one of the two forms of the teaching experiment - the testing (or searching) form. This form of the teaching experiment is used

> ...at the beginning stage of research, when the experimenter, having outlined a hypothesis, does not yet conceive with sufficient clarity the organizational forms of its verification and is working them out in the process of the experiment itself, or when he is outlining a series of variants of the method and wants to determine the most effective of them (Kalmykova, 1966, p. 18).

Inherent within this design are two major components. The first of these is the instructional model that acts as an experimental nucleus for the research. The second component involves the implementation of the model, within an operational classroom, in order to assess its ability to provoke the desired conceptual change within the students. The characteristics of both of these design components will be discussed in this chapter.

The Instructional Model

As stated in Chapter One, the instructional model consists of two elements: first, an instructional strategy, and second, an analytical clue structure. Each of these two elements will be described individually.

The Instructional Strategy

The instructional strategy has four objectives. These are:

1. to explicate the alternate framework that students use when dealing with force/motion (dynamics) events.

2. to have students compare the concepts comprising their alternate framework of dynamics with the Newtonian concepts of dynamics and

(a) recognize conceptual differences, and

(b) clarify the potential sources of these differences.

3. to have students recognize

(a) the limitations of their alternate framework of dynamics as a mode of interpreting force/motion events.

(b) Newtonian conceptions of dynamics as more plausible and productive interpretations of force/motion events.

4. to have students transform their existing mental structure to one more closely approximating the Newtonian framework of dynamics, and use this framework for the interpretation of force/motion events.

In order to achieve these objectives, three complementary tactics have been used.

First, in order to achieve the explication of the components of the alternate framework of dynamics the students were asked to analyze, and draw concept maps (Gowin, 1982) - either individually or collectively - of a series of laboratory force/motion events that are related to dynamics events that occur within the normal, cultural context. These concept maps then served as a focal point for the comparison of student conceptions of dynamics with Newtonian conceptions.

The second tactic used was the juxtaposition of student constructed concept maps with a teacher constructed Newtonian concept map of the same event. This juxtaposition was then used to generate class discussions in which students were challenged to define and/or explain individual concepts that were in conflict with Newtonian conceptions and encouraged to question the Newtonian concepts and their positions within the map.

The third tactic used was the introduction of discordant (in the researcher's opinion) events that could not logically or empirically be explained using their alternate framework(s). These discordant events then served as focal points for class discussions concerning the ability of both conceptual schemes to provide an adequate explanation/solution of the event. In this manner, it was hoped that the Newtonian framework would appear to the students as a more powerful base for the interpretation of force/motion events.

This final tactic was intended to initiate the transformation of the mental structure (represented by the alternate framework) by providing the students with a class of exemplary phenomena that could best be interpreted using the Newtonian framework. These phenomena were all presented as demonstrations and involved the uniform, positive or negative, linear acceleration of objects as a result of the application of a constant force, and objects which travelled with linear, uniform motion as a result of balanced forces. Initially, the phenomena used were divorced from the students' normal, cultural experiences and involved apparatus associated with a school science laboratory. However, as the students became more familiar with the Newtonian conceptual scheme, motion problems more closely allied to the students' normal, experiential base were used (see Appendix I - Student Problem

Sheets). In this way, the transformed mental structure should have more generalized utility and plausibility relative to the original alternate framework of dynamics.

<u>The Development of the Analytical Clue Structure</u>

The development of the analytical clue structure (Roberts & Russell, 1975) involves the representation of a student's inductive knowledge of a specific event or class of events in terms of a set of frames (Minsky,1975) arranged in a generalization hierarchy.

The skeleton of the generalization hierarchy is constructed by connecting each of these frames (representing a specific concept) to the next, more general frame, by an 'is a' link which represents a sub-class/super-ordinate class relationship. Attached to each of the conceptual frames, then, will be sub-classes of concepts, or events which are specializations of that particular frame.

To illustrate this form of hierarchial structure, the reader is asked to consider the general concept 'part(s) of a house'. Attached to this concept, via 'isa' links, would be frames for each of the individual room types in the house, i.e. bedroom, living room, kitchen, bathroom, and so on. Within each frame would be the specialized data that would allow an observer to recognize each room type. Further, these data could include specific, subordinate frames (again attached to the immediate, super-ordinate frame by an 'isa' link) that would allow the observer to differentiate, for example, between formal living rooms and family rooms, and the master bedroom and children's bedrooms. As a result of this type of analysis a structure evolves that represents a template that could be used to determine whether or not a structure could be considered to be a house. Conversely, when this type of structure is derived from an analysis of an individual's inductive knowledge of houses a clue structure develops that provides an interpretative window into what that individual perceives a house to be.

The process of adding substance to and refining the skeletal clue structure, within the context of this research, involves successive applications of the evolving clue structure to student responses to a variety of force/motion events. The student responses to these events are qualitatively analyzed for additional conceptual information that is related to the previously constructed clue structure. This additional conceptual information is then incorporated into the previous clue structure as either sub-classes of existing frames or as new frames. In this fashion, the clue structure undergoes an evolutionary process that results in increasing sophistication and analytical power.

For the purposes of this research, the development of the analytical clue structure has occurred at the level of the individual student. However, where there has been substantial congruence between clue structures derived from a group of students, or where a group of students has been in agreement concerning the specific frames and sequencing of the frames within a clue structure, that clue structure has been interpreted as being generally representative of that student group.

Implementation of the Instructional Model

Implementation of the instructional model occurred within the researcher's own tenth grade science class. Within this class, there were 12 males and 19 females aged 14 and 15 years. Membership in this class was by computer assignment based primarily upon the students' tenth grade course selections. These students had not had any prior, formal instruction in Newtonian dynamics. As a result of these environmental characteristics, this component of the research design represents a case study of the efficacy of the prototypal instructional model. Within this case study environment, the researcher assumed the role of an active participant observer.

The assessment of the efficacy of the instructional model was based upon considerations of its capacity to explicate the students' alternate framework of dynamics and, if necessary, produce the desired conceptual changes within the students. The determination of whether or not these conceptual changes occurred was based upon the researcher's judgement and clue structure analysis of classroom transcriptions and student concept maps. These forms of analyses served as a tracking mechanism for conceptual change within the students and, in this regard, provided a qualitative measure of the effectiveness of the instructional strategy.

Methods of Data Collection and Analysis

Video taping of all classroom sessions provided the primary data. These data were subsequently reduced to a series of transcriptions dealing with particular events within the research sequence. The transcriptions were then analyzed for the major conceptual content and patterns employed by individuals within the class, and a hierarchy of these conceptual data was constructed. These data forms then became the basis for the clue structure analysis.

As the clue structure analysis was applied to the conceptual data frame structures were generated that were intended to represent the major conceptual knowledge pattern(s) that individual students were using to interpret the force/motion events. Where there was substantial support by members of the class for a particular set of conceptual data, the resulting frame was assumed to represent a composite structure that was agreeable to a majority of the class. These frame structures were then used to track the effect that the instructional strategy was having on the conceptual knowledge patterns of the students.

Secondary data were obtained in the form of student generated concept maps and worksheet answers. These data forms were used as a cross-check on the validity of the evolving frame structure(s) by comparing their conceptual structures with those contained in the frame structure.

In summary, this research represents a case study of the effects that an externally designed instructional strategy has had on the conceptual knowledge patterns that students use to make sense of force and motion events. These effects have been tracked using a clue structure analysis of the concepts and conceptual patterns, derived primarily from the analysis of classroom video tapes, that students have exhibited when attempting to explain a variety of force and motion events.

CHAPTER FOUR

The Classroom Case Study

The case study covers eight class periods that spanned a total time period of thirteen school days. Within this period, five specific lessons were presented to the students. These were:

LESSON 1 - An Introduction to Dynamics and Dynamics Terminology.

LESSON 2 - Force Analysis Techniques.

LESSON 3 - The Dynamics of Acceleration.

LESSON 4 - The Dynamics of Deceleration.

LESSON 5 - The Dynamics of Uniform Motion.

Because this case study is primarily concerned with the analysis of the initial conceptual structures that the students were using to interpret dynamics events and any subsequent alteration to these structures as a result of the instructional strategy, only the last three lessons will be presented in this chapter.

It should also be noted at this point that, in a physical sense, there is no verbal distinction between acceleration and deceleration. There is, however, a vectorial distinction with deceleration appearing as a negative acceleration. Due to the age of these students and their lack of scientific/mathematical sophistication, a verbal distinction has been substituted for the vectorial.

Although most physics texts present Newton's Laws of Motion in sequential order, for the purposes of this study, the order was reversed. This decision was based upon previous classroom studies by Minstrell (n.d., p. 61), who found

.... in every class, on every test, the proportion of the class giving Newtonian answers for the accelerating cases was greater than that for the constant velocity cases. Why were the accelerating cases easier for the students to handle? Piaget's theory (1958) suggests that reasoning from the concrete to the abstract is easier than from the abstract to the concrete. The concrete firsthand experience in the instruction dealt with situations involving acceleration, Newton's Second Law. It seemed logical that the constant velocity case, involving Newton's First Law, should be taught as a logical consequence of the acceleration case.

Because the focus of this research is the elicitation and alteration (if necessary and possible) of students' conceptions of motion, the case study was concentrated on data collected from the last three lessons. The data from these lessons will be introduced in two formats.

The first data form is transcriptions of class discussions concerning motion events that are presented to provide a flavour of the classroom environment, and a macroscopic view of initial student conceptions and any subsequent alterations to these conceptions. Included within these transcriptions are concept maps constructed by the class as a result of their discussions of force and motion events. These concept maps are presented to allow a visual examination of the major concepts being employed by these students to interpret these events.

The second form of data to be presented is interpretational, conceptual frames constructed by the researcher to account for attempts by individual students and/or the class to interpret specific types of motion. The use of these interpretational frames allows a more in-depth examination of the elements of the alternate framework and provides a means of identifying any subsequent alteration to this framework as a result of the instructional strategy. The method of constructing these interpretational frames will be more fully discussed later in this chapter.

The Lessons

The Dynamics of Acceleration

The lesson was begun by asking the students why an object, such as a dynamics cart, would begin to accelerate and continue to accelerate?

Kelly:
Because there is more force pushing it than there is friction going against it. The reason is (pause) friction is trying to stop it...(inaudible).
Teacher:
Is that force always there?
Kelly:
No (pause) Yes, it would have to be, depending on how long, how far you wanted to accelerate it for.
Teacher:
We're going to keep the thing accelerating for as long as we want.
Kelly:
Then the force always has to be there.
Teacher:
So there has to be a continuous force applied to the object, and the force has to be larger than (pause)?
Kelly:
than the friction.
Teacher:
What do the rest of you think about that? Is that the cause of acceleration? (pause) Any other ideas about acceleration? Is it caused by a continuous force?
Cory:
It increases.
Teacher:
So, the force is getting larger?
Cory:
Yeah.
Teacher:
All the time (pause) so the force is always getting larger, and larger, and larger?
Another student:
Yeah.
Cory:
Yes.

At this point, student idea generation tended to abate. In order to refocus them, both Kelly's (acceleration is a result of the continuous application of a constant force) and Cory's (acceleration is a result of the application of an increasing force) concepts of the cause of acceleration, were written on the blackboard. Kelly was asked for further clarification of her concept.

Teacher:
Kelly, correct me if I'm wrong, that force is always the same size is that right?
Kelly:
Yeah.

This clarification caused many of the students to become agitated and vocally disagree with Kelly's concept of a constant, continuous force causing acceleration. In the face of this unsubstantiated disagreement, Kelly volunteered a further clarification.

Kelly:
It's still continuous force. If you keep the friction on at the same level, then it's still continuous force but, ah, the continuous force is getting harder. It's pushing more.
Teacher:
Is that what you mean by this statement (referring to Kelly's original concept of the cause of acceleration that had been written on the blackboard).
Kelly:
Yeah.
Teacher:
So your continuous force is a continuous, increasing force.

Kelly, however, was not completely willing to cast aside her original idea that acceleration might be caused by a continuously applied, constant force. She finished the debate with a further qualification.

Kelly:
...or you can have a continuous force with a decrease in the friction force.

At this point in the lesson, there was overall class agreement with the idea that an object (in this case a dynamics cart) would accelerate if an increasing, continuous force was applied to an object as long as the frictional force remained constant and smaller than the applied force. This spirit of classroom consensus was carried over to the construction of an embryonic concept map that attempted to relate accelerated motion to force (see Figure 1).

The next class began with a review of the acceleration concept map that the students had generated at the end of the previous class. This map was then juxtaposed with a teacher-constructed map of Newtonian concepts of acceleration (see Figure 2) and the students were asked to compare and comment upon the two maps.

Teacher:
The real difference (between the two maps) is, if you apply a constant force will you get acceleration? If you apply an increasing force, will you get acceleration?
Jim:
Yeah.
Teacher:
Yes? In both cases?
Jim:
Yeah.
Teacher:
Why?
Jim:
Because you're still applying a force.
Teacher:
So even if the force I'm applying is constant, it is still going to accelerate?
Jim:
Yeah, it's larger.
Teacher:
Interesting! Kelly, you came up with this yesterday (see lines 23 to 25, p. 35) what do you think about that?
Kelly:
Yeah, especially on the stationary one.
Teacher:
So you're going to agree with this too. Even if the force is constant?
Kelly:
Well, ah (pause), what I don't think is (pause) it's the moving object, right. (pause) You said they were doing this

Figure 1. A Map of Students' Concepts of Acceleration

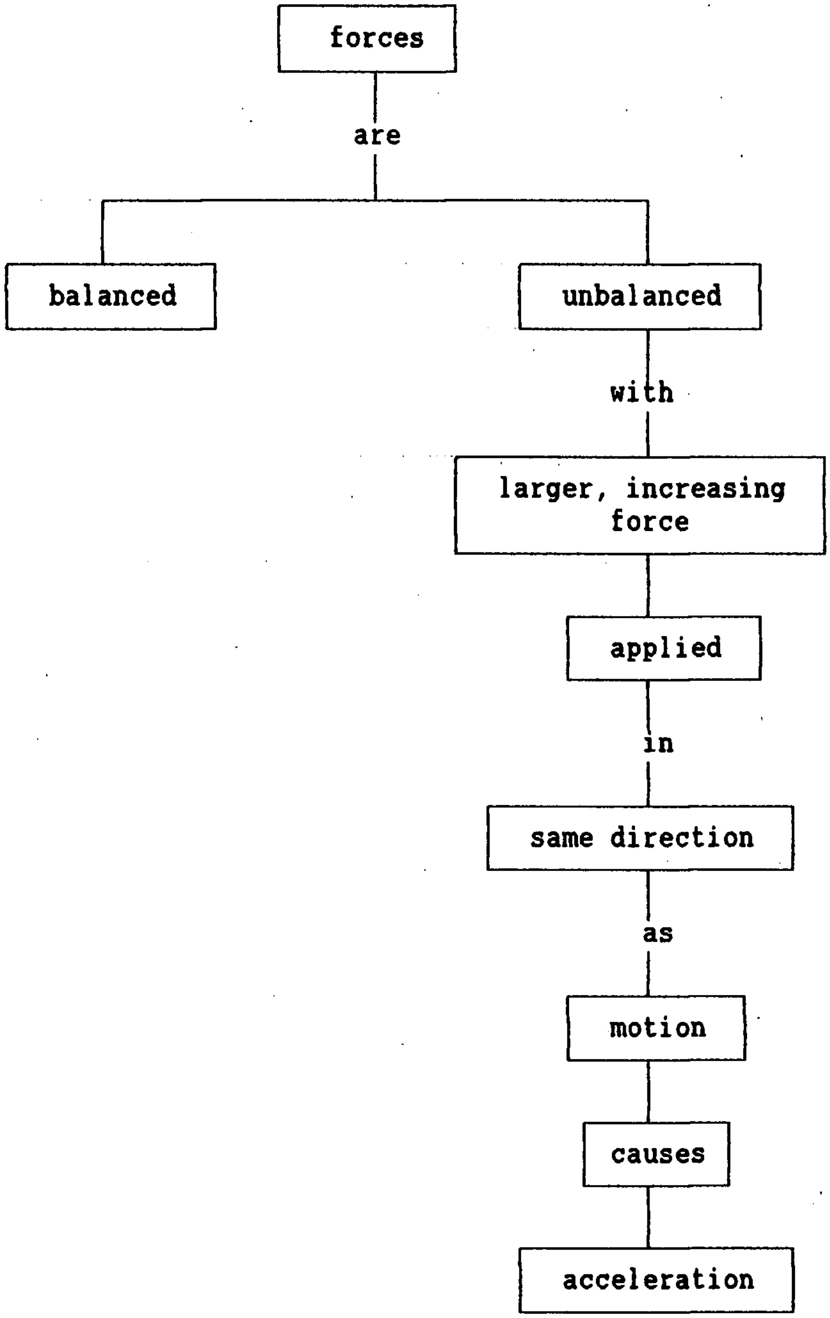
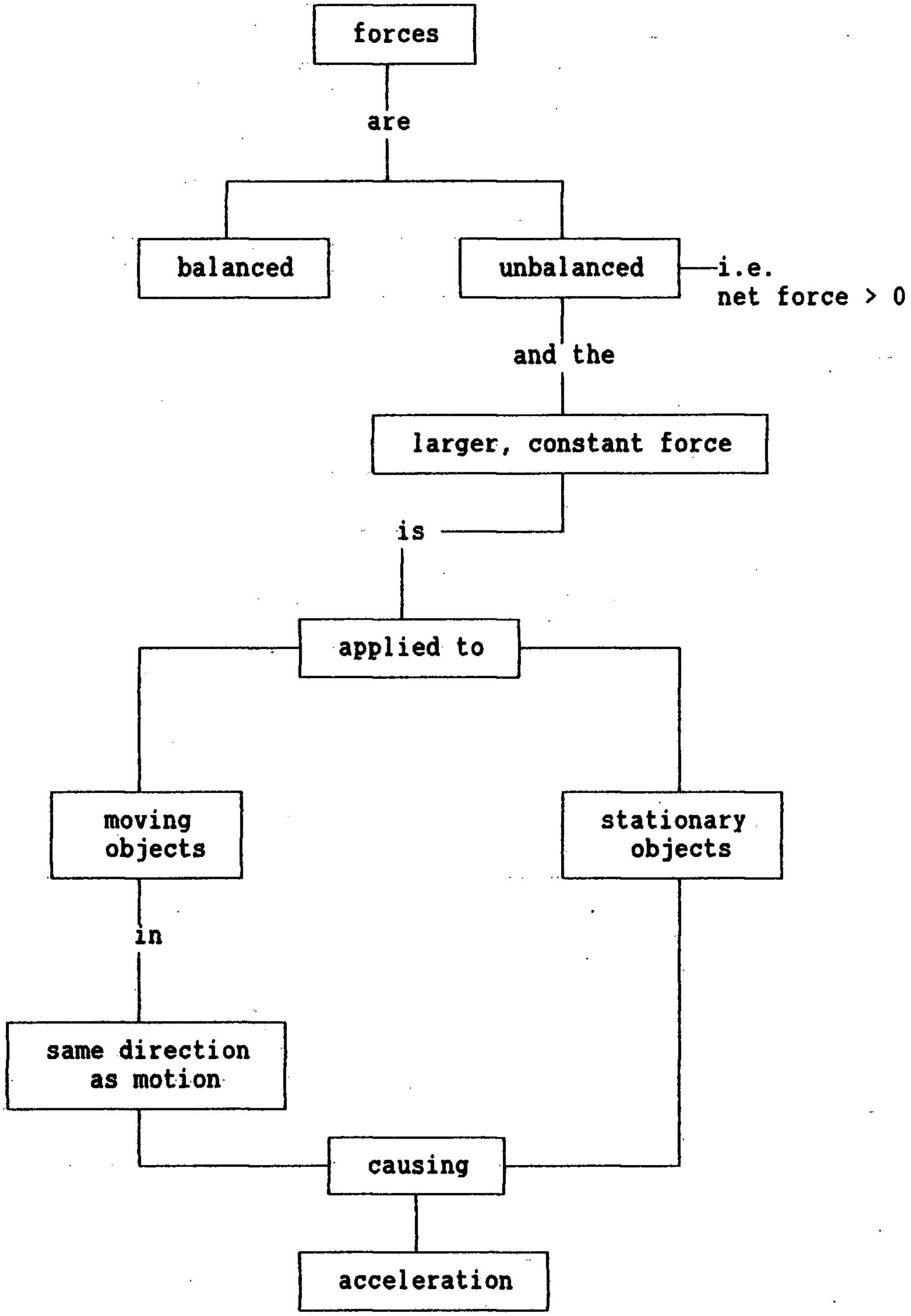


Figure 2. Teacher-constructed Map of Newtonian Concepts of Acceleration



for as long as they wanted to go for, right? (obtains confirmation from the teacher). (pause) If you pushed 50 N on something for ah (pause) like a length of time, its first bit is going to accelerate and then stop.

Melanie (interjecting):
If it's a constant force, it will stay constant!

Teacher (addressing Kelly):
So you feel that there is going to be a point where, even though that force is constant, you're going to back off to a constant velocity after awhile.

Kelly:
Yeah.

Teacher:
Melanie, you had something to say.

Melanie:
If you have a constant force, then you'll have a constant velocity.

Teacher:
So you're going back to this theory that we came up with yesterday, that constant force ends up with constant velocity. You must have an increasing force to come up with acceleration.

Melanie:
Yeah.

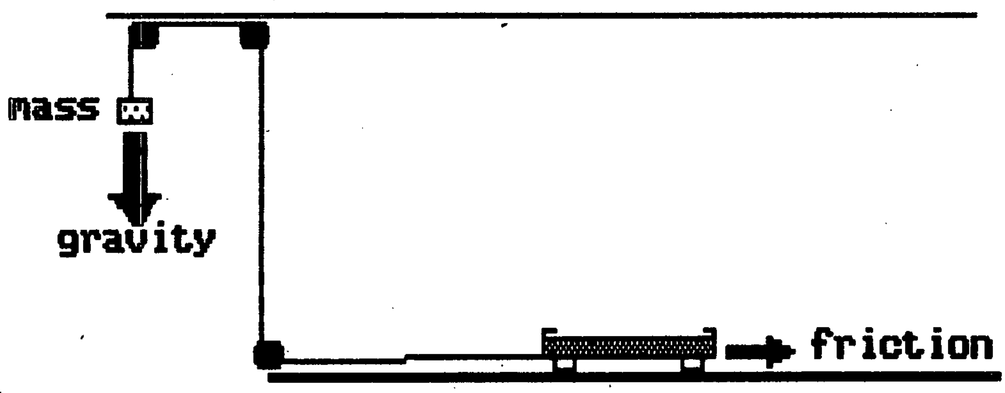
It appeared, at this point, that the students were wedded to the concept that, if an object was to accelerate continuously, a constantly increasing force would have to be applied to that object. The union, however, was not without its flaws for both Jim and Kelly had suggested that acceleration would occur if a constant force was applied to an object. Although, in Kelly's case, qualifications had been applied to the concept. Two demonstrations were presented to the class in order to provide them with physical situations that would emulate both conceptual schemes.

The first demonstration consisted of an equipment trolley that was being pulled by a student. The friction on the trolley had been estimated by measuring the amount of force required to just begin the trolley moving. The force that the student was applying to the trolley was measured with a spring scale graduated in newtons. The class was asked to closely observe the motion of the trolley.

Three trials were made with this equipment. The first two trials involved starting the trolley from a motionless position and then pulling it with (a) a continuously increasing force, and (b) a constant force of 20 N. The third trial involved the application of a constant force of 20 N once the trolley was moving. In all cases, the students unanimously agreed that the trolley accelerated.

The second demonstration involved applying a constant force of approximately 5 N to a dynamics cart using a system of pulleys that allowed a 500 g mass to fall under the influence of gravity (see Figure 3). Again, the class unanimously agreed that the application of this constant force caused the cart to accelerate.

Figure 3. Acceleration Demonstration #2



At first pass the instructional strategy appeared to have the desired effects. The initial demonstration (of an accelerating dynamics cart) and the subsequent discussion of the cause(s) of this acceleration had exposed the students' general conception of acceleration. This was that acceleration was caused by a continuously increasing force applied in the same direction as the initial motion. Additionally, this conception suggested that the majority of students would also adhere to the generalized belief that any form of motion must imply some application of force for, if acceleration was caused by a continuous application of increasing force, then uniform motion should logically be caused by an application of constant force. Whether this, in fact, would be the case would have to wait for the lessons dealing with uniform motion.

That part of the instructional strategy that was intended to alter the student's generalized conception of the dynamics of acceleration appeared to proceed flawlessly. When faced with empirical evidence from the demonstrations there was unanimous agreement that acceleration would be caused the application of a constant force applied in the same direction as the initial motion. What was disturbing about this event was that the conversion from the first belief structure to the second appeared to occur without any form of mental dissonance on the part of the students. Considering the vociferous disagreement that had resulted from Kelly's original suggestion that acceleration was a result of the application of a constant force (see lines 23 through 25, p. 35), it was difficult to believe that the students would relinquish their hold on their original conceptual structure so easily. Was it possible that the demonstrations had convinced the students that the minimum condition necessary for acceleration to occur was an application of a constant force and that their original conception was a subset of this, or were these two conceptual structures now coexistent in the minds of the students and context sensitive? One structure, acceleration requires a continuously increasing force, to be used for experiential/real world circumstances, and the other, acceleration only requires a constant application of force, to be used for their science class. The resolution of the possible interpretations had to wait until the clue structure analysis of the class discussions.

The Dynamics of Deceleration

The discussion of deceleration was initiated as a natural corollary to the students' previous discussion of acceleration. While discussing what would happen to the motion of a car if the force supplied to the drive wheels was reduced by half while keeping the frictional forces constant (but less than the force supplied by the drive wheels), the question was posed - how could you get this car to begin to slow down. In other words, under what conditions would the car decelerate?

Teacher:
If this is acceleration (referring to a diagram of a car, on the board, with the force from the driving wheels being larger than the frictional force), how do you get deceleration? How do you get the car to slow down?
Kelly:
Make the friction larger than the force.

(Teacher draws another diagram of a car on the blackboard and reiterates the question.)

Teacher:
How do you get deceleration? You want to slow this guy down.
Jim:
Decrease your push force.
Teacher:
How much are you going to decrease it? If I was going to draw a push force up here (referring to the diagram) would it be smaller than this (referring to the frictional force), larger than this, or the same size?
Jim:
It's going to be larger.
Teacher:
It's going to be larger. Any other ideas?
Dina:
(inaudible)...it'll be smaller so that friction will slow it down.
Teacher:
Why does it have to be smaller?

Dina:
So that the friction overpowers the push force.
Teacher:
Jim, what do you think about that?
Jim:
(inaudible)...it will stop it.
Teacher:
If I draw this arrow up here (referring to the push force) to be larger than the frictional force, am I going to end up with this situation over here (pointing to the acceleration diagram)?
Jim:
Yeah.
Teacher:
Am I still going to be accelerating?
Jim:
Yeah. It'll be deceleration from your constant speed ...(inaudible)...you're not going to stop ...(inaudible).

Two, diametrically opposed concepts of the causes of deceleration have emerged from this discussion. Kelly and Dina feel that deceleration occurs when the frictional (or opposing) forces on an object become larger than the motive force, whereas Jim feels that deceleration occurs when the motive force decreases in magnitude, but still remains larger than the frictional forces. Kelly's and Dina's idea that the net force on the object must be in the opposite direction relative to an object's motion is a logical extension of the conclusions, previously arrived at by the students, concerning the cause of acceleration. Jim's idea, on the other hand, is in direct contradiction with these conclusions but in keeping with the 'motion implies a force' structure recognized in the acceleration lesson. Indeed, Jim apparently doesn't see any contradiction between the position he has taken on deceleration and his previous statements on acceleration (see lines 1 through 11, p. 36). Jim is resolute in his belief and suggests that Kelly's and Dina's concept will cause the object to stop. When asked to reconcile his concept with the agreed upon force diagram of acceleration Jim further suggests that a reduction of the motive force (albeit, keeping the net force in the same direction as the initial motion) will result in deceleration but will not stop the object.

Jim's belief appears to be a consistent subset of the concept that acceleration is caused by an ever increasing force. If an ever increasing force is replaced by a decreasing force surely deceleration must result.

The robustness of this belief suggests that Jim is basing his concept on personal, experiential evidence. This type of evidence could be collected while driving a car. If the car was accelerating and the gas pedal was then slightly released (the motive force was reduced) the rate of acceleration would decrease. This decrease might then be interpreted as deceleration with the motive force still being applied in the direction of motion.

The rest of the class had, so far, not entered into the debate on the possible causes of deceleration. In order to elicit any further ideas or arguments, both concepts, regarding acceleration, were restated and the students' opinions were solicited.

Jody:
The push force is going to be larger (than the frictional force) but smaller than it was before.

(Teacher draws a diagram of a car on the blackboard, next to the diagram that the class has agreed represents acceleration, with the motive force reduced in magnitude but still larger than the frictional force.)

Teacher:
30 There's the push force. Is it larger than the frictional force? Is the net force still in the same direction of the motion? The question is - is that (pointing to the new diagram) going to have the same effect as this (pointing to the acceleration diagram)? This results in acceleration

(pointing to the acceleration diagram). What does this (pointing to the new diagram) result in?

Jim:
Deceleration and then acceleration.

Teacher:
Any other ideas?

Jim:
Well, this is just an example. When you push your pen like this and slowly slow it down (Jim demonstrates with his pen on the lab bench) and you're still moving; so, you took off some of the push force but you don't stop it.

Teacher:
Suppose I took this push force and I shortened it up (makes the modification to the diagram). I made it smaller than the frictional force.

(At this point, a number of unidentified students volunteered answers to the question that hadn't yet been asked. They suggested that the car would (a) stop, or (b) decelerate.)

Kelly:
Its going to decelerate. The friction force becomes stronger than the push force and then, sooner or later, its going to stop if you keep it at that, and its going to stop and it will be a balanced force...(inaudible)...after it stops.

Teacher:
Interesting! Why do you think that is going to occur?

Kelly:
Because the push force is less than the friction force and (pause) unless (pause) if it's going along a level road it can't keep its motion up.

Jim:
Um, I think that if you weren't moving there wouldn't be any friction...(inaudible)...the friction would go down to zero.

Teacher:
So, the slower you are moving, the less will be the friction force.

Jim:
Yeah.

Teacher:
I just want to get back to something that Kelly said a minute ago. Ah (pause) she said that this (pointing to diagram in which the motive force is less than the frictional force) is going to result in deceleration and, ultimately if it keeps going on, this is going to stop and reverse its direction. Is that correct?

Kelly:
Reverse its direction? No! It will just stop!

Teacher:
In this situation (referring to the previous diagram), what
is the direction of the net force going to be?
Jim:
What do I think?
Teacher:
No, what is it going to be? The way it's drawn right now.
Tawnia:
It'll be one way for awhile then, when it starts decelerating
(pauses).
Teacher:
Let's put some numbers on this. This might help you. Let's
say that the friction, in this case, is 100 N. The push
force from the wheels is 50 N. What is the actual size of
the net force going to be?
Kelly:
50 N.
Teacher:
OK. 50 N. Which direction is it going to be in?
Many students:
Left to right!
Teacher:
Going that way (indicating a direction opposite to the motion
direction).
Many students:
Yeah!
Another student:
Opposite to the direction.
Teacher:
So the net force is 50 N, and it is in that direction (makes
adjustment to diagram on the blackboard). Now, you've got
two competing possibilities here. Either this (pointing to
the diagram with the net force applied in the opposite
direction to the motion direction) causes deceleration or,
the other situation, which had the push force being larger
(than the frictional force) causes deceleration.
Tawnia:
How could that (referring to the latter case) cause
deceleration?
Teacher:
Well, that's what we're going to test out.
Jim:
Well, friction can't be stronger than the push force because
everything...(inaudible).
Teacher:
Brad, you're disagreeing.
Brad:
Friction can be larger than the push force because, when you
put your foot on the brake it stops because of friction.
Teacher:
OK. Tawnia, then Carla.
Tawnia:
When you're talking about deceleration and have the
push force being larger (than the frictional forces).
Does that work by when (pause) the force is applied but

it is not constant. I mean, you have to have a constant
force to keep it accelerating but, if you just have a
push force larger that's not constant then you're going
to decelerate...(inaudible)

Teacher:
Do you mean it's fluctuating? It's getting larger then
smaller and then larger and smaller?

Tawnia:
If it's constant it's going to stay (pause), it's going
to accelerate but, if it's not constant it's going to eventu-
ally decelerate.

Teacher:
What I'm interested in is what you mean by 'not constant'?

Tawnia:
Um, OK. When you just push something and you just let it go.
Is that what you mean by the push force being larger because
it's not a constant force but it is going to decelerate.

Teacher:
See, in that case, when you let it go, I would say that there
is no push force on it at all.

Tawnia:
Then how can it decelerate if a constant force is applied to
it, with the push force being larger?

Teacher:
The push force being larger

Tawnia (interjecting):
and a constant force, how can it decelerate?

Teacher:
That's my question!

Tawnia:
You said that we were going to test that out.

Teacher:
That's right.

Tawnia:
But that can't happen!

Jim is not without supporters in the class. Jody, for one, appears to agree with Jim's conception that deceleration requires a reduction in the motive force while still keeping it larger than any opposing forces (see lines 28 and 29, p. 44). In addition, some other students agree with Jim's idea that, if the motive force becomes less than the opposing forces, an object will stop moving.

Kelly and Dina also find support within the class. Tawnia, in an attempt to rationalize her acceptance of the idea that acceleration is achieved through an application of constant force, points out the logical inconsistency of Jim's argument (see lines 100 through 125, pp. 46 and 47). She finishes with a most definite prediction for those who believe that acceleration can occur during those times when the net force is opposite to the direction of motion - "But that can't happen!".

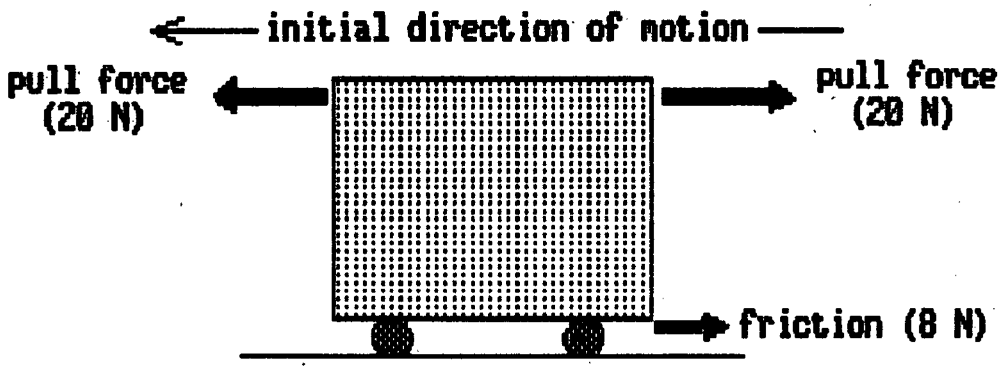
What isn't clear at this stage is, which of these two views represents a majority position within the class. In order to crystallize the debate, the students were presented with another hallway demonstration. As with the acceleration demonstration, an equipment trolley was used as the moving object with the forces being supplied by the students. This demonstration began with a recreation of the acceleration demonstration. The trolley was then repositioned and a student began pulling it with a constant force of approximately 20 N. When it was clear that the trolley was accelerating, a second student began pulling, in the opposite direction, with force of approximately 20 N. This retrograde force, when combined with the frictional force of approximately 8 N, provided a net force of 8 N applied in the opposite direction to the initial motion (see Figure 4). When asked to describe the type of motion that resulted from this situation, a majority of students agreed that the trolley decelerated.

The class ended with this demonstration and any further discussion was deferred to the next class.

The next class began with a diagram of the previous demonstration (see Figure 4). The students were then asked to comment on the type of motion that resulted from the resolution of forces.

Teacher:
What kind of motion did that trolley exhibit at that point?
Cindy:
Deceleration.

Figure 4. Deceleration Demonstration #1



Teacher:
Now, before we go any further, is there any disagreement on the observation? Did everyone see that (referring to the trolley) decelerating or, did anyone else see one of the other of the two other types of motion - as travelling with a constant velocity or travelling with acceleration?

Jim:
Well,ah, (pause) it was decelerating but, after it was finished decelerating it was at a constant velocity.

Teacher:
OK. So you saw it decelerating and, then you saw it travelling with a constant velocity?

Jim:
Yeah. Well, they didn't go long enough. It was starting at the end.

Teacher:
So, if we had allowed it to go longer, you think it would have started to travel with a constant velocity. So do you agree with Cindy, with the first part, that there was deceleration there?

Jim:
Well, it slowed down.

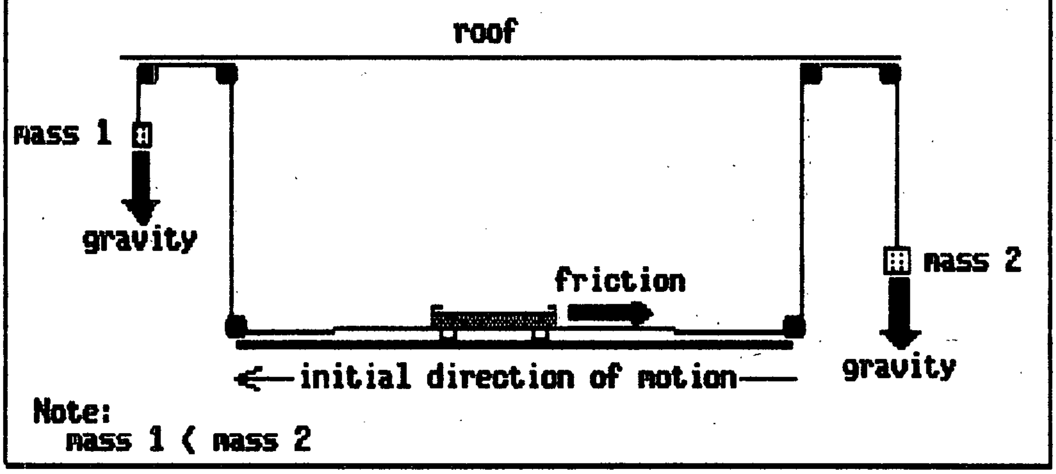
Teacher:
OK. Any other observations?

In the face of dwindling peer support and empirical evidence to the contrary, Jim has made significant modifications to his theory of decelerating motion. Previously he had argued that decelerated motion was a function of a reduced motive force, however, the net force still remained in the same direction as motion. Additionally, this force situation would not, ultimately, result in a cessation of motion but, rather, some form of forward motion would still be in effect. After this demonstration, he has now grudgingly adopted the position that deceleration is a result of the net force opposing the original direction of motion. However, he is not willing to completely abandon his previous interpretational frame. He finishes this discussion of deceleration by suggesting that, under these new set of conditions, uniform motion will be the result when the deceleration is completed and, that, in fact, was what he saw. When pressed on this observation he equivocates, but strongly suggests that the demonstration wasn't allowed to continue to its logical end.

The class consensus appeared to favour the concept that deceleration occurred when the net force was in the opposite direction to the motion of an object. This consensus appeared rather vigorously during the next demonstration.

This demonstration was a variation on the second acceleration demonstration (see Figure 3). In this case, however, a mass had been added in such a way that a net force was applied in the opposite direction to the cart's motion (see Figure 5). When asked to predict what type of motion would be displayed by the cart under these conditions, a number of students replied, with some indignation, that the cart must decelerate. After the demonstration concluded, these same students suggested (with an 'I told you so' air) that deceleration was self-evident under these conditions and that further demonstrations were pointless.

Figure 5. Deceleration Demonstration #2



An episode occurred towards the end of this class, however, that illustrated how fragile and context-sensitive the students understanding of deceleration dynamics really was and how close to the surface the concept of 'motion implies a force' existed.

At the end of the first class on deceleration the students had been assigned a deceleration worksheet which was to be due for this class. The questions on this worksheet were discussed after the final deceleration demonstration and, with the exception of the final problem, appeared to present few difficulties to the students. The final problem (shown below as Figure 6) was a different matter.

Teacher:
    What are the forces acting on that ball Kari?
Kari:
    Gravity.
Teacher:
    Is that the only force?
Kari:
    No.
Teacher:
    Is there another force?
Kari:
    Friction.
Teacher:
    The direction that gravity is operating in Kari?

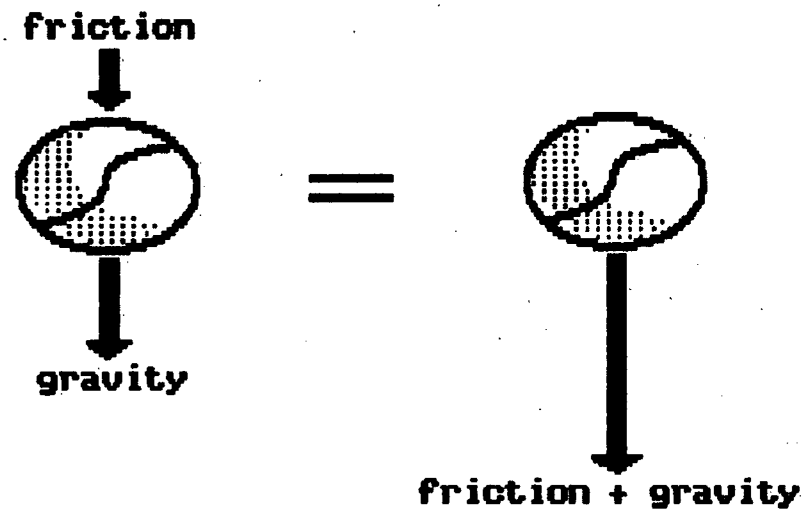
Figure 6. The Final Deceleration Problem

A baseball player has just hit a foul ball. The ball is travelling vertically upwards. On the diagram below, draw the force (or forces) that are acting on the ball and which are parallel to the direction of motion. In addition, describe how the ball is moving i.e. is it accelerating, decelerating, or travelling with a constant speed?

Kari:
Um, down.
Teacher:
The direction that friction is operating in?
Kari:
In the opposite (pause) as gravity.
Teacher:
Gravity is operating down, the ball is going up. Which direction is the friction operating in?
Kari:
Oh, the ball is going up. Down.
Teacher:
OK. Friction is operating in that direction. Can I simplify this diagram any right now?
Kari:
Yes, you can include friction and gravity as one.

Kari has provided a correct force analysis of the problem. Indeed, she has displayed a fair level of sophistication for this grade level by recognizing that multiple forces operating in the same direction can be collapsed into a single force (see Figure 7). This analytical sophistication, however, is a didactic veneer that Kari (and other students) subsequently stripped off to reveal an experiential core based upon Impetus Theory.

Figure 7. **Kari's Force Analysis**



Teacher:
Ok, so we have a net force downward?
Kari:
Yeah.
Teacher:
Does everybody see what I'm doing with that. Just combining
the two because they're in the same direction.
Another student:
What about the push force?
Teacher:
OK. Just hang on. (The teacher makes the necessary adjust-
ments to the diagram on the blackboard.) OK, Kari, any other
forces on there?
Kari:
Yeah. The push force going up.
Teacher:
What push force?
Kari:
Um, um, from the ball.
Teacher:
Is there anything pushing the ball?
Another student:
The bat!
Teacher:
The bat is down here (indicating a region below the black-
board).

At this point, the class became very agitated and many students attempted to provide an answer to this problem.

Teacher:
Hold it! Now wait a minute! Wait a minute! I'll get too each of you, one at a time.
Melody:
Mr. Brace! Listen to this! (Melody begins to read out the problem, but slowly trails off and stops before finishing it.)
Teacher:
Has the ball left the bat?
Many students (including Melody):
Yeah.
Teacher:
Are there any other forces on the ball?
Melody:
No, there are no other forces. Just the forces going downward.
Teacher:
Michelle.
Michelle:
A push force.
Teacher:
Where is the push force coming from?
Melody (interjecting):
Well what are you going to call the force (directed at Michelle)?
Teacher:
Hold it. Wait a minute. Is there a contact force involved here?
Another student:
Yeah, there was.
Teacher:
You're saying there is a contact force?
Another student:
Was! There was!
Teacher:
Past tense? Is that contact force still there?
Many students:
No!
Michelle:
The push force is still there, but the contact isn't.
Teacher:
Now wait a minute. How can you have a push force without a contact?
Brad:
As the soon as the ball left the bat, the force, um, there was no more force and the ball immediately started to decelerate.
Teacher:
So you're saying at this point there are no other forces on here (referring to Figure 6)? We have a motion going upwards, and the only forces are gravity and friction operating downward.
Another student:
Then how can it be going upwards?

Another student:
That's impossible!

Balls being batted or thrown into the air have been common, childhood experiences for the majority, if not all, of these students. It is clear from the debate that has taken place that almost all of these students have constructed an explanation for the upwards movement of objects (under these conditions) that is consistent with Impetus Theory. The strength with which they put forth their arguments suggests that it is almost inconceivable to them that some object could move upwards against the combined forces of gravity and fluid friction without some kind of force to push it. This experientially constructed explanation is so concrete to these students that they appear to not have heard and/or accepted the force and motion analysis of this system but, instead, have immediately opted for their own internal presumption of the dynamics of the system. Only Brad appears to have heard the initial force analysis with an open mind and has correctly related this to previous deceleration demonstrations. Aside from this one comment, however, he did not enter into the debate that continued to rage around him.

Teacher:
Hold it! Wait! Wait! Carla you were next. We're going to
go Carla, Kelly, and then back to you guys.
Carla:
(inaudible) when you slowly press on the brakes it'll slowly
go to a stop. When the bat hits the ball, the ball will go
up and slowly (pause), eventually (inaudible).
Teacher:
So you agree that there is deceleration.
Carla:
Yeah.
Teacher:
Do you agree with this type of diagram, that the only
forces operating on here are gravity and friction and they
operate as a net force vertically downward?

Carla:

(inaudible) Yeah.

Teacher:

OK. Kelly.

Kelly:

The ball moving is the end result of the contact force. I don't know what you call that though. What do you (pause). You tell us. Is there a name for a force after the contact force? The ball's still moving. The ball's going is the end result of the contact force. But the contact force is over with but its not going (inaudible).

Teacher:

What has been the result of the contact force? Let's try and (pause).

Kelly:

The motion of the ball upwards.

Teacher:

OK. So that's taken care of right here (referring to the diagram), and your position right now is that there is no longer any contact force. That has been translated into a motion. Do you agree with this situation (that the ball is decelerating as a result of the net force opposing the direction of motion) in so far as the other forces?

Kelly:

Yeah.

Teacher:

OK. A couple of more points. Tawnia.

Tawnia:

When the ball leaves the bat there's a contact force. Its just like pushing and pulling down the hallway (referring to the hallway demonstrations). You let it go and it just keeps going and the friction acts on it and it decelerates. Its going to happen with the ball. There was a contact force. It'll move because of the contact force and it will slow down because of friction. So the only forces that were acting on it was the contact force, at the beginning, then the friction acts on it right away. And after the contact force there is only a friction force.

Teacher:

Is gravity operating on there or not?

Tawnia:

Yeah.

Teacher:

OK. So you want to include gravity. OK, you guys.

Kari:

I don't understand. If there's no force now how come its still going upwards? It will eventually go down but there still has to be some sort of force on it to make it continue to go upwards.

Teacher:

Can you come up with some place where there is an upwards force on the ball? Are there any field forces or contact forces pushing upwards?

Kari:

Not at the moment.

Melody:
What are you going to call it? There has to be some force pushing it up.
Teacher:
Why does there have to be a force?
Melody:
It wouldn't move anywhere!
Kari:
Don't forces cause motion?
Teacher:
Definitely!
Kari, Melody, and Tannis (together):
Well, its moving!
Kelly (interjecting):
Well, there was a force. There was a contact force that caused the motion (inaudible).
Kari:
I know that!
Teacher:
Kelly I want you to explain that position to those guys.
Kari and Tannis:
We know that!
Melody:
What are you going to call it?
Kari:
Say that you were told that there was friction force and gravity force acting on this ball, you would think that it was going down. But no its not, its still going up!
Teacher:
Remember what you said before about the initial motion. Now once you start the initial motion and then apply a force in the opposite direction what type of motion do you come up with?
A student:
Deceleration.
Teacher:
OK, let's follow this right through to the end.
Melody:
Its decelerating when its going up.
Kari:
I understand it Sir. I'm just saying what do you call it.
Teacher:
I know. I'm trying to stay away from the label for a minute. I want to go right through this process.
Melody:
Then we understand it.

In so far as this context is concerned, the 'motion implies a force' structure and its corollary, Impetus Theory, are firmly entrenched in these students. Only Tawnia (see lines 95 through 106, p. 56) and Brad (see lines 57 to 59, p. 54) appear to have analyzed the situation in the light of the previous demonstrations and lessons, and can accept that there can be motion without a continuous motive force. For the remainder of the students who took part in this debate however, if a ball is moving upwards there must be some force pushing it upwards.

These students do, however, appear to be wrestling with an interesting dichotomy. On the one hand there is their almost unshakable belief that motion is directly tied to a continuous motive force. While on the other hand they have been provided with empirical evidence that applied, net forces can be operating in the opposite direction to the motion of an object. Compounding this paradoxical situation is the realization (among some of the students) that they have stumbled into a logical trap. They have agreed with the analysis of the forces acting on the ball but now must find some other phantom force to buttress their contention that, in this case, the ball can only move upwards if there is a force pushing it upwards. Their cries for help in resolving this conflict are clear throughout the latter stages of this debate. Kelly (lines 78 through 83, p. 56), Melody (lines 116 and 128, p. 57), and Kari (line 139, p. 57) all ask for a name for the force that they assume is causing the motion of the ball. Its as if a name, provided by the teacher, would provide them with a warrant that would validate their experiential theory concerning the upward motion of the ball. When that name is not forthcoming, closure to the debate is provided by Melody (see line 142, p. 57) who appears to be giving notice that she is now prepared to play the school game. The game, in this case, is that there are 'right' answers to school questions, but the real answers are to be found elsewhere.

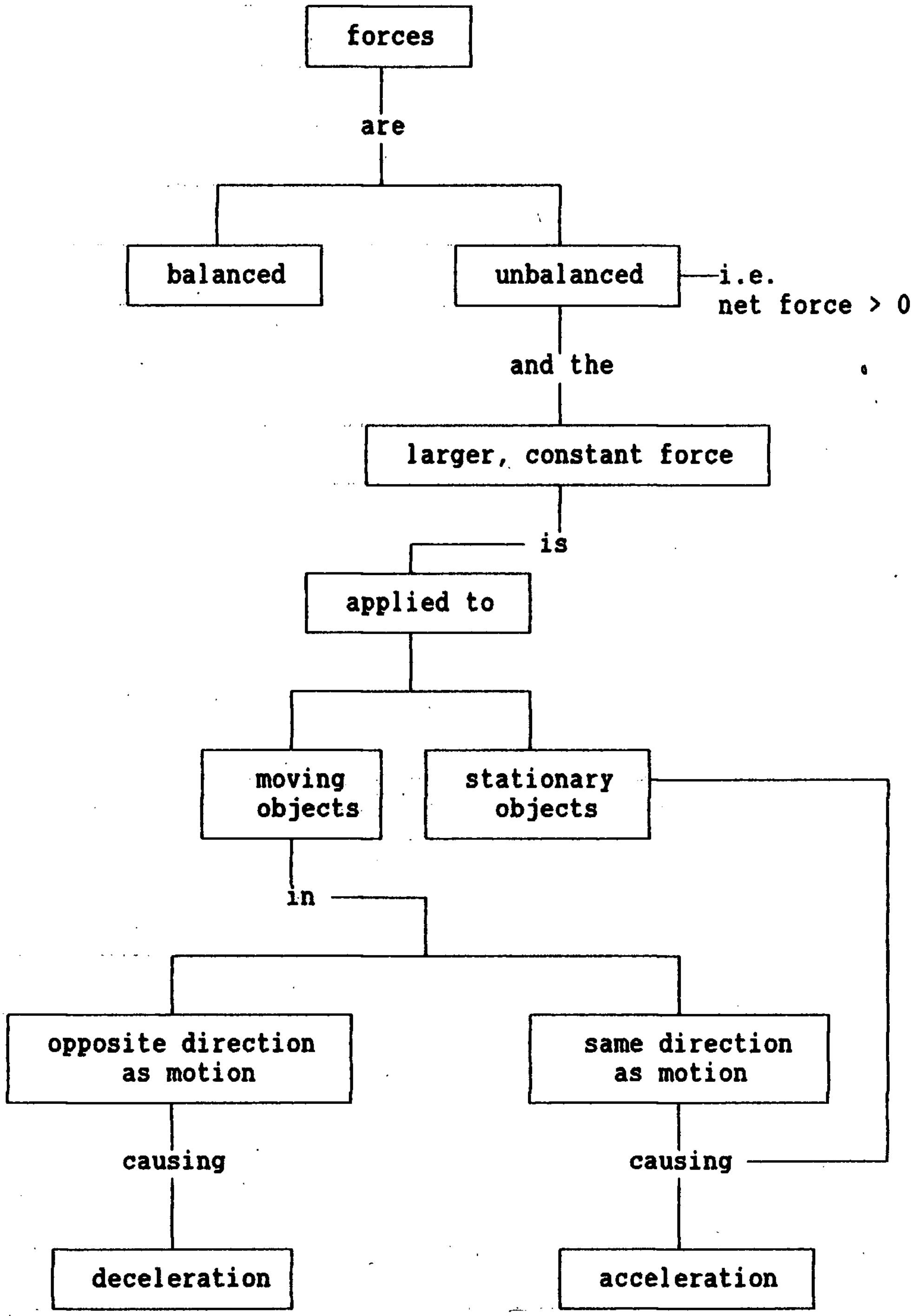
The Dynamics of Uniform Motion

The emergence of the 'motion implies a force' belief as the predominant conceptual structure in the final discussion of deceleration did not provide an auspicious entrance to a study of uniform motion. The anticipated strategy for this section of the study had been to utilize the students' appreciation of Newtonian concepts of acceleration and deceleration as a logical foil against the emergence of the 'motion implies a force' belief during the discussions concerning uniform motion. The premature (from an instructional point of view) appearance of this structure however, tended to throw this strategy into disarray. After a number of attempts to redesign the strategy to fit this new environment, it was decided to retain the original strategy with one modification. This modification involved an attempt to reinforce the Newtonian concepts of acceleration/deceleration (and by doing so, deemphasize the 'motion implies a force' frame) by engaging the class in an extension of their existing acceleration concept map to include the deceleration concepts.

Student discussion leading up to and during the redesign of the acceleration concept map was perfunctory. It was as if the debate in the previous class had never occurred, and it was an insult to their intelligence to be discussing, again, a set of concepts that was so self-evident. The redesign of the acceleration concept map (see Figure 8) was achieved rapidly with no debate or dissent.

The discussion of uniform motion began with a definition - uniform motion is travelling with a constant speed. Again the vectorial component of this concept was ignored due to age and lack of mathematical sophistication of these students. The students were then asked for

Figure 8. Redesigned Concept Map of Acceleration and Deceleration



their ideas concerning what set of conditions could result in an object travelling with a constant speed.

Dina:
When a constant force is applied.

It was pointed out that this situation, according to the concept map that the students had just generated, could only result in acceleration or deceleration depending upon the direction that the force was being applied in.

Again the question was posed.

Kari:
A decelerating force.
Teacher:
You mean its getting smaller and smaller and smaller? (Kari nods her head in agreement). Well, if one force (the larger force in a force pair) is getting smaller and smaller what happens to the net force?
Brad:
It becomes equal.
Teacher:
Ultimately it will become equal. Equal to what?
Brad:
(inaudible) a car won't decelerate or accelerate. It will just stay at one speed.
Teacher:
OK, but if you have one force here and one force there, and they're are both the same what's the net force?
Many students:
Zero.
Teacher:
Is that going to cause uniform motion?
Brad:
Yes.
Teacher:
So you feel that if the net force is equal to zero then you'll end up with uniform motion. (Brad nods his head in agreement.) So what your saying then is that if there is no force, no net force operating on an object (pause).
Brad:
Well, there was. Now there isn't, so it stays at the same speed.
Teacher:
So if it travels at a constant speed net force is zero.

Brad has exhibited a high level of analytical sophistication and analogic reasoning to arrive at his conclusion concerning the dynamics of uniform motion. Whether his solution is pervasive among or acceptable to the rest of the class remains to be seen.

Kari:
I don't believe that. If you have balanced forces then it won't be moving.

Teacher:
OK. Why do you think it won't be moving?

Kari:
Because it has an equal amount of force pushing against each other. If they're the same strength they're not going to push each other.

Teacher:
Brad, you were pretty definite that they were not going to move (sic). Why not?

Brad:
I said it was gonna - it won't decelerate or accelerate. It has to accelerate before uniform motion and then the forces will balance out and stay at uniform speed.

Teacher:
Are you two talking about the same set of conditions? When you're taking about travelling with uniform motion, that object that's going to be travelling with uniform motion, was it moving to begin with or was it stopped to begin with?

Brad:
It would be moving to begin with.

Teacher:
Then your position is then that if you take a moving object and you apply balanced forces to it then you end up with uniform motion.

Brad:
Yes.

Teacher:
Kari was your object

Kari (interjecting):
Still.

Teacher:
It was still to begin with. So we have a different set of conditions.

Kari:
But I think if we have balanced forces it'll decelerate.

Teacher:
Why will it decelerate?

Kari:
Because the forces are equal and they're, I don't know, they're going to want to stop.

Brad:
They're not going to stop.

Tawnia:

That's right (apparently agreeing with Kari).

Teacher:

So, in essence, what you're saying is that there is a requirement for a constant force to keep something moving. Is there a problem with this then (referring to the concept map)? In this case it appears that a constant force results in acceleration or deceleration.

Kari:

Maybe I don't believe in uniform motion then.

Teacher:

Brad did you want to say something.

Brad:

Well, when an object moves with uniform motion it can't speed up or it can't slow down so there are no forces (inaudible) to speed it up or slow it down.

Brad is apparently in a minority position within the class in so far as his explanation of the causes of uniform motion. Kari, Dina, and Tawnia represent the (supposed) majority view that a null net force condition does not contribute to uniform motion and, by inference, if there is motion (uniform or otherwise) there must be a dominant force present.

In an attempt to break the hold that the 'motion implies a force' belief had over the class a demonstration was presented. This demonstration was given in two parts.

The first part of the demonstration was designed to demonstrate the effect of balanced forces on a stationary object - in this case an equipment trolley. Not surprisingly the students were able to correctly predict and accept the outcome of this event.

The second part of the demonstration was designed to demonstrate the effect of balanced forces on a moving object, again an equipment trolley. In this case the trolley was initially accelerated by a student and then a second student supplied an equal force in the opposite direction. Before the demonstration began the students were asked to predict the motion of the trolley when only one student was pulling it. All of those students that replied indicated that the trolley should accelerate. After a number of practice attempts to familiarize the students who were supplying the forces with what was expected of them, and to ensure that the trolley would follow a straight path, the class was asked to closely observe the motion of the trolley after the second, equal but opposing force had been applied.

Teacher:
Heinzy, what type of motion did you think it was travelling with once it passed this point where Cory started applying the force in the opposite direction.
Heinzy:
It slowed down.
Teacher:
As it moved that way towards the camera did it continue to get slower and slower?
Heinzy:
It stopped at one point and stayed at that point.
Teacher:
I'm sorry?
Heinzy:
Or, it kept at a constant speed.
Teacher:
So there was a period where it appeared to slow down and then it travelled with a constant speed.
Heinzy:
Yeah.
Teacher:
Steve, what do you think? You felt it slowed down first and then (pause)
Steve:
kept going at the same speed.
Teacher:
Kari?
Kari:
Yup. Uniform motion.

The class was almost at an end. It had been a class that had singularly lacked the energy and vitality that had been so evident in the final discussions of deceleration. It was as if the majority of the class was playing Melody's 'school game'.

Although the demonstration appeared to have convinced the students that balanced forces applied to a moving object resulted in uniform motion there was a sense of unease in the class. This uneasiness was perhaps typified by the comments that Tawnia and her lab partner Kirsten made as they were preparing to leave the class.

Tawnia:
Is that right Mr. Brace?
Teacher:
How do you mean - is it right?
Tawnia:
When you're moving and you apply balanced forces then you travel at a constant speed?
Teacher:
What did you see happening?
Tawnia:
Well I don't know? I don't even know if they (the students who were applying the forces to the trolley) were applying balanced forces.
Teacher:
Well they were being pretty careful. I think you can assume that they were applying balanced forces.
Tawnia:
So that's right then.
Kirsten:
Then why wouldn't it stop?
Tawnia:
Yeah.

The 'motion implies a force' belief was lurking just below the surface and Tawnia was on the verge of succumbing to it's seductive attraction (as were, probably, many other students). Her attempt to obtain a warrant from the teacher concerning the 'rightness' of the concept that balanced forces would produce uniform motion was an attempt to reduce the tension and uneasiness that must have been building within her and throughout the class. A tension and uneasiness that stemmed from the conflict between what her experience suggested was true and the conceptual path that her teacher wanted to lead her down. When that warrant was not explicitly forthcoming and, instead she was asked to reexamine her own observations, she has replied (with

Kirsten's support) with an apparent acceptance of the 'motion implies a force' belief.

The last class in the dynamics unit was devoted to tackling, head-on, this underlying sense among the students that all motion, and specifically uniform motion, must be caused by some form of applied or indigenous force. The class was begun by reviewing the demonstration from the previous day and randomly selecting students to explain what they thought caused uniform motion. Consistently the students responded that uniform motion resulted when the net force on an object became zero. A class straw vote resulted in unanimous agreement with this concept. The sense of unease, prevalent in the previous class however, remained. It was as if the students were parroting back what they thought was expected of them. In an attempt to draw out and confront what was assumed to be an almost subliminal, intuitive belief in the 'motion implies a force' concept the students were presented with one final series of demonstrations.

The first demonstration consisted simply of pushing a dynamics cart across the floor and then removing the push force.

Teacher:
    If I push this cart along the floor and I let it go, the
    question is what would the force or forces be acting on the
    cart? Before we get to the force or forces one thing I'd
    like to know is what kind of motion is the cart going to
    exhibit?
Many students:
    Acceleration.
Teacher:
    OK, Kelly.
Kelly:
    Acceleration.
Teacher:
    Any other predictions?
Kirsten:
    Deceleration.
Teacher:
    You figure its going to slow down.

Many students:
After. Yeah, after.
Teacher:
OK. Its going to accelerate then decelerate.
Kelly:
And if it has enough room its probably going to end up stopping.
Teacher:
Kirsten, are you saying its going to decelerate as soon as I let go.
Kirsten:
Yeah.
Teacher:
OK. Any other predictions?

No other predictions were forthcoming so the cart was pushed and released.

Teacher:
Now, after I let go (of the cart) and before it ran into that desk leg over there, what forces were acting on it?
Kelly:
You've told us that one (inaudible).
Teacher:
About inertia. OK, inertia is not a force. It's just a tendency of things to keep on doing whatever they are doing before.
Kelly:
There's friction. There's rolling force (friction) and, um, air.
Teacher:
OK. So's there's just (pause).
Kelly:
Oh yeah, there's gravitational pull.
Teacher:
OK, but we're only interested in those forces that are operating parallel to the direction of motion.
Kelly:
OK, then there is the rolling and air friction.
Teacher:
So there's just friction. Is the push force still there or not?
Dina:
No. Not after you left it. Not after you let it go.
Teacher:
So once I let it go there's just a frictional force on it. If there's just a frictional force operating on it, which direction is the frictional force operating in?
Another student:
In the opposite direction to motion.

Teacher:
OK. Take a look at that concept map (see Figure 6) over there. If the only force operating on this after I've let it go is the frictional force, operating against the direction of motion, what type of motion should this exhibit?
Kelly:
It should decelerate. (pause) It should but it doesn't.
Teacher:
Why should it?
Kelly:
Because if you think about it there's only friction (pause), I don't know.

Kelly is convinced that she saw the cart accelerate after the push force was removed. This isn't that surprising because that is what she predicted would happen (see line 8, p. 66). On the other hand she has recognized the logical inconsistency that she now finds herself in because she had just correctly analyzed the forces operating on the cart to be only frictional forces which must slow the cart down. At this point, however, she appears to be unable to rationalize this tension between her perceptions and her analysis. She is not alone in this conflict.

Teacher:
Kirsten, why did you say it would decelerate in the first place?
Kirsten:
I don't know why, I just think it would.
Teacher:
You've got this gut feeling that it will. Kari.
Kari:
(inaudible) If the net force is opposite to the direction of motion the object is supposed to decelerate.
Teacher:
Now, if that's the case - the only force on here is the frictional force - why would it accelerate to begin with?
Kelly:
Because of the push force you gave it in the first place. If you give it a push force and its going to last for a certain length of time. Its not going to just (pause)
Michelle (interjecting):
Its not going to just decrease because the contact force you've pushed on it is going to make it accelerate and then it'll decelerate.

Teacher:
...Now the suggestion's been made that what happens to this cart is that it speeds up initially and then it starts slowing down... Now if its going to speed up, then how do you make something speed up? What do you have to do to its net force?

Brad:
Make it larger and constant.

Teacher:
OK. We've got to make larger and constant. At least constant. That's the bare minimum that we can do. The problem is, if I've let go of that thing, where is that larger force coming from?

Another student:
From friction.

Teacher:
OK, but I don't think that anybody is in disagreement with the fact that there is friction on here. What's been suggested is that I move this along and I let it go and it starts speeding up. The suggestion's been made that the reason it speeds up is because I've transferred some of my force on to the cart.

Michelle:
Yup.

Teacher:
Now, how many people think that is the case?

A straw vote was taken to determine how many students felt that some amount of force had been transferred to the cart and had caused the initial acceleration. In other words, how many of the students were operating from an 'Impetus Theory' base. A clear majority of the students felt that this was the case.

Teacher:
Now, if that's the case, then if I remove the friction what should happen, if there is a transfer of force, is that it should keep accelerating. Is that right?

Many students:
Right.

Teacher:
OK. Let's remove the friction.

This was the introduction to the second demonstration. This demonstration used an air-track to reduce friction to a negligible amount. The method of operation of the air-track and its effect on the sliding friction of the air-track rider was explained and demonstrated to the students.

Teacher:
Now the suggestion is that there is a transfer of force from whomever or whatever is doing the pushing to the object that is being pushed. I want you to remember one thing. If you're going to deal with good science what you're going to have to be able to do is demonstrate that, after the initial push force has left, there is a force on the object. Otherwise, if you can't demonstrate that it is there you can't say that it is there.

At this point the air-track was turned on and the rider was given an initial push force down the track.

Teacher:
OK. Where is the push force on the rider now (the rider was travelling through the central portion of the track)?
A Student:
The air (from the air track) is pushing it.
Teacher:
Now wait a minute. The air is going out that way (indicates an upwards direction).
Melanie:
Well your force is still on there.
Teacher:
OK. If my force is on there where is it?
Dennis:
In the air.
Teacher:
No the air is going up. The motion is going that way (indicates a direction 90° to the airflow).
Melanie:
Its pushing in the direction that you pushed. Its still there. Like its still pushing. It just can't stop (inaudible).
Teacher:
Well my question to you is - where is it?
Melanie:
Its in the rider pushing it forwards.
Teacher:
But what's pushing?
Melanie:
Nothing.
Teacher:
Can you demonstrate that there is something pushing that rider?
Melanie:
There's nothing. Its from the friction or something.

Teacher:
But we've reduced the friction.
Melanie:
Well I don't know.

What had initially started out as an analytical debate had quickly degenerated into a circular argument that appeared to be irresolvable. This lack of resolution was beginning to frustrate both the teacher and the students. In a final attempt to break through the circle, the students were led through a detailed force and motion analysis of the rider and asked to consider what kind of motion the rider should display if, in fact, it was carrying some form of indigenous force.

Teacher:
Now do you need a larger force, in other words a net force greater than zero, to have something moving?
Melanie:
Yes. No! You don't.
Teacher:
If the net force is zero what type of motion do you have?
Melanie:
Stationary.
Teacher:
What type of motion do you have?
Melanie:
Uniform motion.
Teacher:
OK. Is this thing (the rider) exhibiting a uniform motion?
Another student:
Yeah.
Teacher:
If its exhibiting a uniform motion what do you know about the net force on it?
Many students:
Its zero.
Teacher:
Now if the net force is zero you've got one of two situations. There is a frictional force on here (the rider) - that way. Then there must be an inherent force on here (the rider) that I gave it.
Melanie:
Yeah. That's what I told you.
Teacher:
But why am I using this machine?
A Student:
It reduces the friction.

Teacher:
Right! So if I've reduced the friction there is no force there.
Melanie:
There's still force there (on the rider) though.
Teacher:
But if there's force on the other side (of the rider) it should be accelerating.
Melanie:
No, because your force is dying down. Its not a constant force.

No amount of argument, logical or otherwise, will convince Melanie that there are no motive forces attached to the rider. She espouses an almost classical Impetus Theory when she finishes her argument with the statement that the force is "dying down" (see line 140, p. 72). For her, objects only move when they are forced to move. If no recognizable force is present on a moving object then its because there has been a transfer of force to the object and this force will get used up during the motion thus causing the object to slow down and ultimately stop.

At this point other students began to enter the debate with their own explanations for the movement of the rider.

Brad:
There wouldn't be any friction (referring to the air-track).
Teacher:
There is no sliding friction. You're right.
Brad:
So as soon as you let it go there won't be any forces acting on it at all. So it will be travelling with uniform motion.
Teacher:
Kelly.
Kelly:
The force that you gave it - like there's no friction or anything - it took that force. If you gave it 10 N of force, and its going to keep that. Its just going to keep it. Its (the force) not going to run off....If there is no friction it'll keep going at a constant (pause).
Teacher:
If you have a constant force applied in the direction of motion according to that (the concept map) it should accelerate.

Kelly:
Yeah, but you're not giving it a constant force. You just gave it that one initial push...that first push force you gave it 10 N, right, and you're not giving it a constant force so that its just going to keep that 10 N because there's no friction now. So its going to keep it because there's nothing to stop that 10 N, so it'll keep going.

Teacher:
But isn't that a constant force? If there is a force on there of 10 N all the time shouldn't it accelerate?
OK. We're going to go to Heinzy, Tawnia, and then over to (inaudible). OK, Heinzy.

Heinzy:
The force decreases to zero and since there's no resistance going the other way it keeps going.

Teacher:
With what type of motion?

Heinzy:
Uniform motion.

Teacher:
So you're saying the net force is zero after I let it go.

Heinzy:
It decreases to zero.

Teacher:
OK, and because the net force is zero we're dealing with uniform motion.

Heinzy:
Yeah.

Teacher:
Ok. Tawnia.

Tawnia:
You said that acceleration is (a result of) a push force going in the direction of the motion that is bigger than the other force?

Teacher:
No, I've gone back up to this concept map right over here. There's a larger constant force applied to moving objects in the same direction as the motion and that causes acceleration.

Tawnia:
I know. Well that's what's happening. The net force is going the same way as the direction.

Teacher:
Then this (the rider) should be accelerating.

Tawnia:
Yes.

Teacher:
Does it?

Tawnia:
No.

Teacher:
If it doesn't (pause).

Tawnia:
Then that (the concept map) is a bunch of crap!

Teacher:
Then there is one of your two options. Either that thing is wrong or
Tawnia (interjecting):
We've learned this all wrong then.
Teacher:
Why are you assuming that? Did that concept map work for your other demonstrations?
Another student:
Yeah, it did.
Teacher:
Well if it did why would you throw it out just because it doesn't appear to work for this one. What's your other option here?
Kari:
That this (the rider) has no forces acting on it.
Teacher:
That's the other option. Right! Now once I let it go there are no other forces acting on it.
Kari:
And if there are no forces then the net force is zero, therefore it has uniform motion.

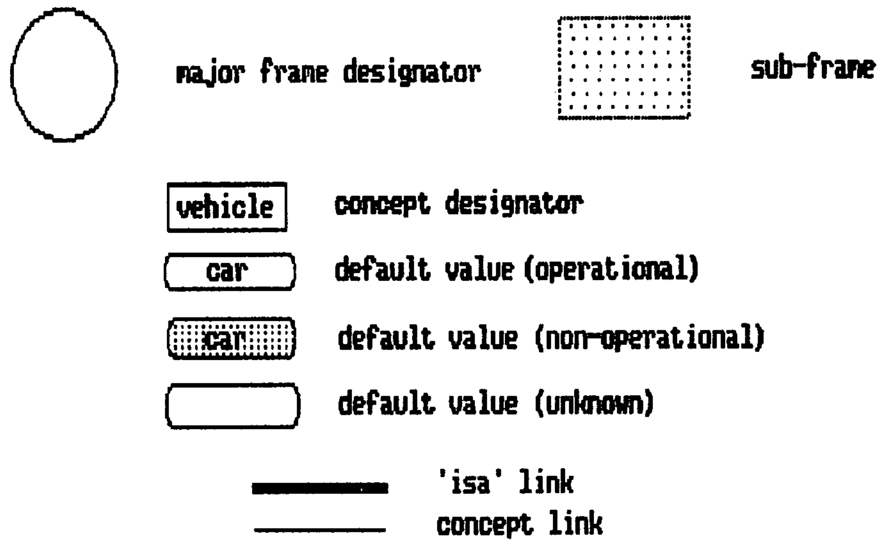
The class ended with Kari's description of the Newtonian option. An option that few of the students appeared to be willing to consider.

Throughout this class the frustration level of both the teacher and students had risen to an almost palpable level. On the one hand, the teacher felt stymied by his inability to move the majority of the class towards an acceptance of the Newtonian option. On the other hand, the students appeared frustrated by their inability to obtain validation, from the teacher, of their interpretation of the events that they had just witnessed. An interpretation that was, to them, strongly self-evident and based on the experiential axiom of the 'motion implies a force' conceptual structure and its corollary Impetus Theory.

A Clue Structure Analysis of the Effectiveness of the Instructional Strategy

The clue structure analysis of the effectiveness of the instructional strategy was composed of two phases. The first phase consisted of analyzing the lesson transcripts for the conceptual data that the students were using to interpret the force/motion events that had been presented to them. These conceptual data were then reconstructed into diagrammatic, interpretational frames on an individual and composite basis. The symbols used to represent the various elements and connectors within the frame structures are shown in Figure 9.

Figure 9. Symbols Used In Frame Constructions



Within the set of elements that have been used for the reconstruction of the interpretational frameworks, the concepts of frames, sub-frames, and default values have been discussed previously. The differentiation of the default values into those that are operational, non-operational, and unknown , however, have not been previously described. These descriptions will occur at this time.

As mentioned previously, default values are specific, discrete, and idiosyncratic data that are applied to the interpretation of an event or object. As an example of this data type, the conceptual frame for 'car' would contain a default value for the number of wheels that an individual perceives a car to have which, in most cases, would be 'four'. For the purposes of this research, those default values that are playing an active role in an individual's interpretation of an event or object will be referred to as 'operational'. Those default values that are interpreted (by the researcher) to exist within a specific frame, but are not playing an active role in an event or object interpretation will be referred to as 'non-operational'. Default values that are classified as being 'unknown' are those that, in the researcher's view, are present in an individual's interpretation of an event or object but cannot be directly derived from the transcriptions.

The second phase consisted of comparing the 'before instruction' frame structures with those that appeared 'after instruction'. This comparison then allowed a subjective assessment to be made of the instructional strategy's ability to modify students' conceptual understanding of the dynamics of motion to one more closely approximating the Newtonian conceptions of motion. Each of these two phases will be discussed individually.

<u>Student Interpretational Frames of Motion</u>

Throughout the discussions on motion the students repeatedly focussed on two elements: the initial state of the object that was to be moved or in motion, and the forces that were perceived to be responsible for the motion. This binary nature of the discussion suggests that for these students, at least, any frame dealing with motion is composed of two sub-frames; one sub-frame to deal with the object and the other to deal with forces. This stage of the analysis is directed towards delineating the components of these sub-frames and the interactions between the sub-frames.

Acceleration

The discussions concerning the dynamics of acceleration explicitly involved four students - Kelly, Cory, Jim, and Melanie.

Kelly's opening arguments as to why an object (in this case a dynamics cart) would begin to accelerate and continue to accelerate consisted of the following concepts:

1. The object must have a push force applied to it (see lines 1 to 3, p. 34).

2. The applied push force must be larger than any frictional force operating in the opposite direction (see lines 1 to 3, p. 34) and, by implication, the push force must be in the same direction as the motion.

3. The applied push force must be continuous (see line 9, p. 34).

4. The applied force must be constant (see lines 23 to 25, p. 35).

Kelly subsequently modified her fourth point to clarify when an application of a constant force would result in acceleration. This modification was based upon the state of the object and indicated that if the object was initially stationary an application of a constant force would accelerate that object (see line 14, p. 36). If, however, the object was already in motion the application of an additional force would accelerate the object but only for a finite period of time. By the end of that period whatever acceleration had occurred would have degraded to a constant velocity state (see lines 16 to 27, pp. 36 and 39). By implication then, if one wished to have a moving object continuously accelerating (linearally or otherwise) a continuously increasing force would have to be applied to that object. Figures 10 and 11 diagram the probable frame structure and usage of this structure.

Another student's (Cory) comment that a continually increasing force is required for acceleration (see lines 13 to 22, p. 34) appears to be directed at the second part of the original question (Why would

Figure 10. Kelly's Acceleration Frame for Stationary Objects

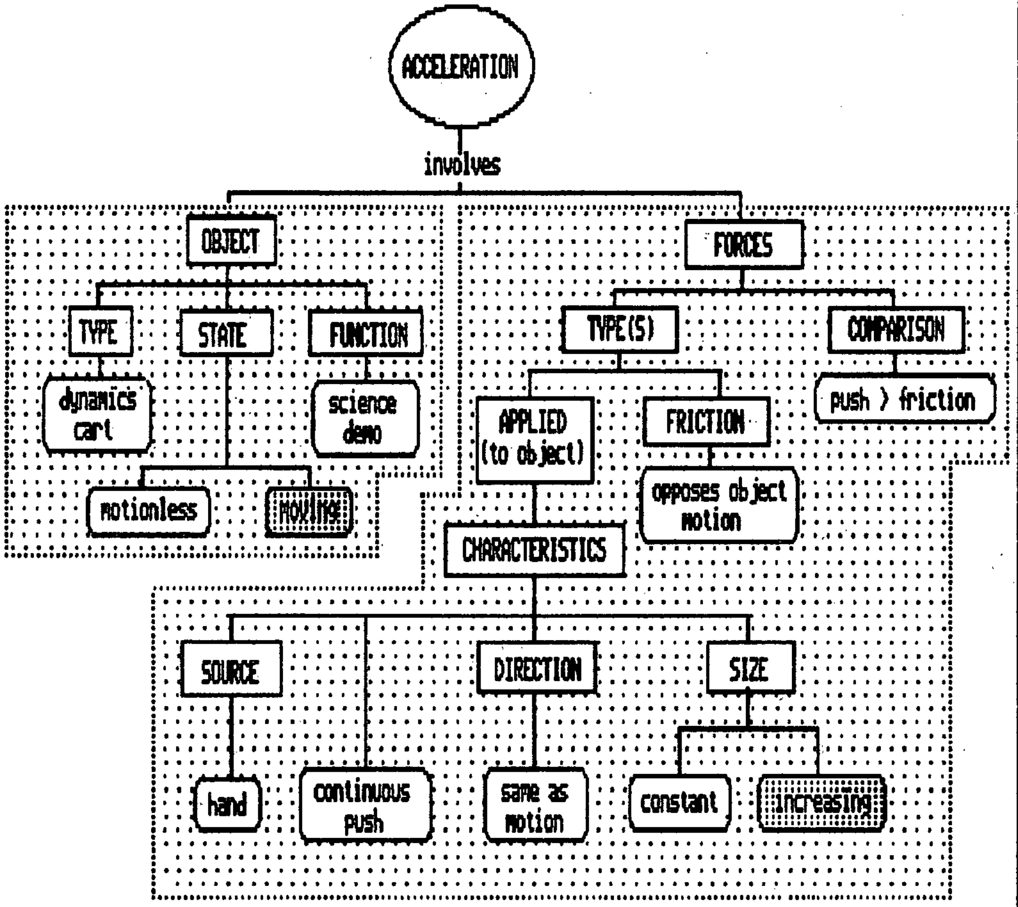
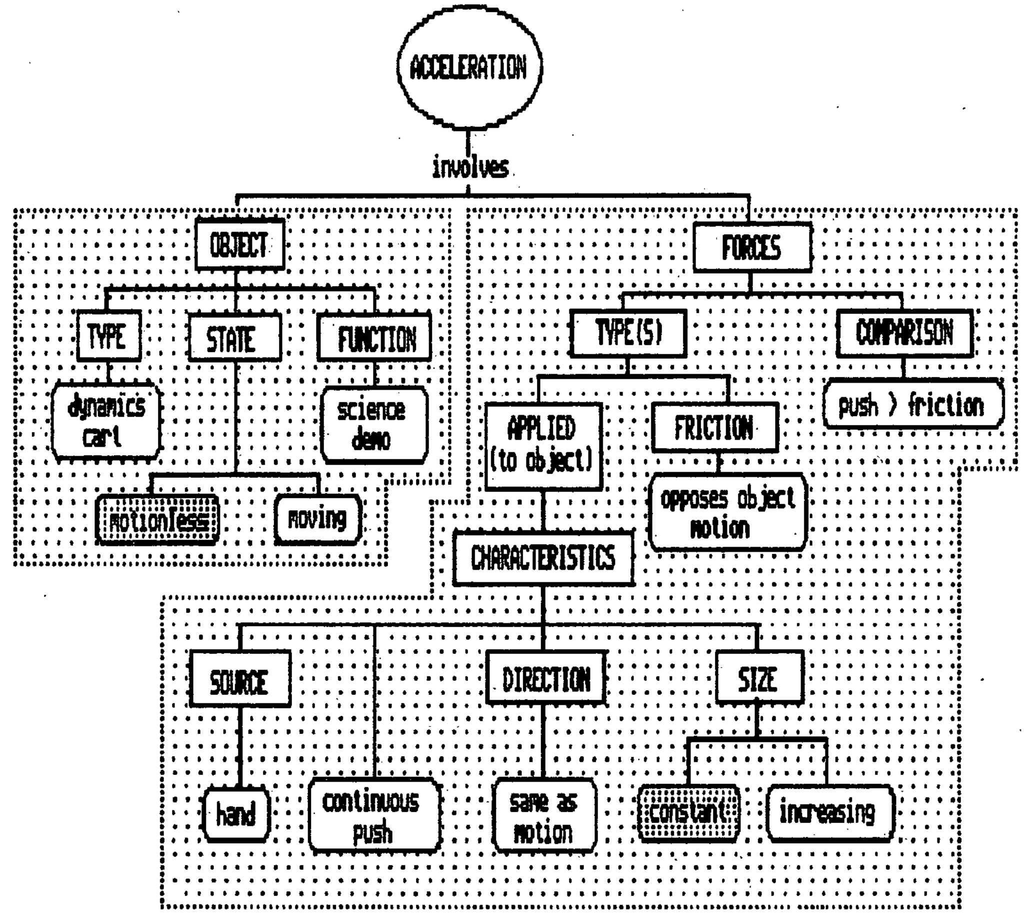


Figure 11. Kelly's Acceleration Frame for Moving Objects



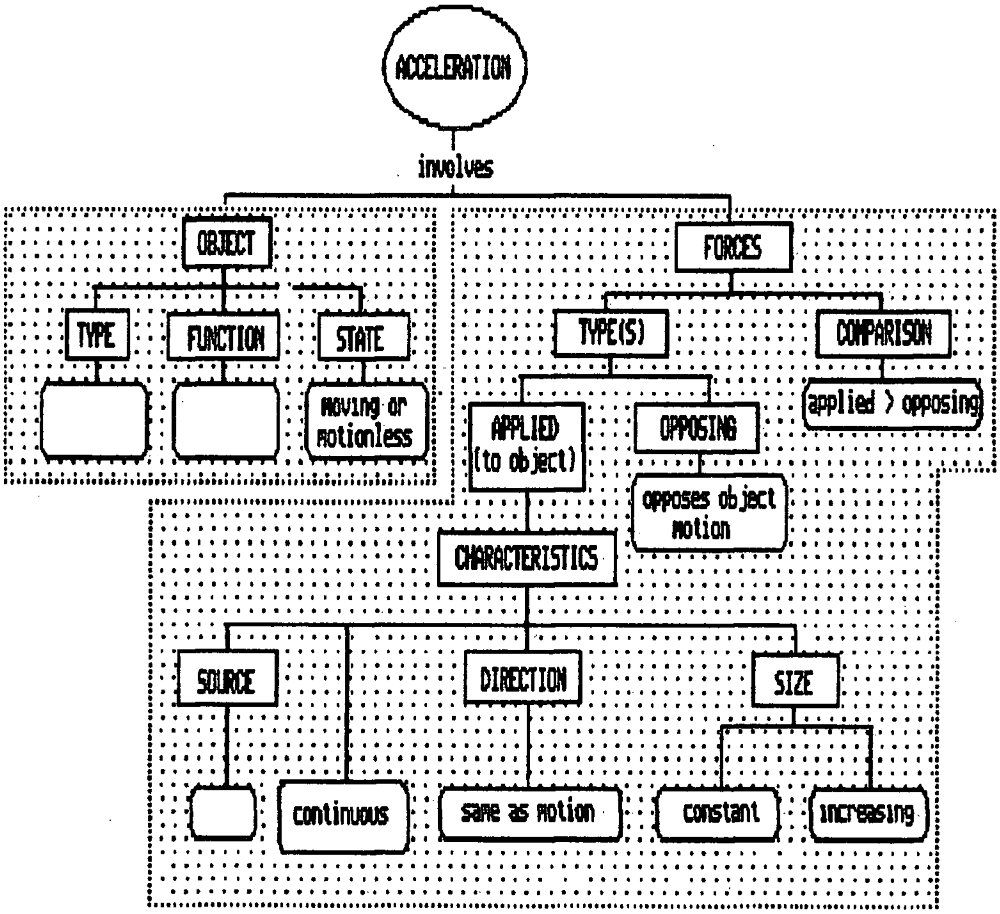
an object continue to accelerate?) asked by the teacher. His comments have been made within the context established during the interchange between Kelly and the teacher that have dealt with the conditions necessary to keep a moving object accelerating. As such he appears to be in agreement with, at least, that part of Kelly's frame that implies that if an object is already moving acceleration can only be achieved by applying a continually increasing force.

In a similar fashion Melanie also appears to agree with at least the implied part of Kelly's acceleration frame. As with Cory, Melanie's comment that a constant force will result in a constant velocity (see lines 29 and 30, p. 39) has occurred within the context of a discussion concerning the acceleration of a moving object. As with Kelly, Melanie has implied that acceleration of a moving object can only occur with the application of a continuously increasing force.

Jim is the odd man out in this discussion. His comments (see lines 1 to 11, p. 36), made during the comparison of the class and teacher produced concept maps, suggest that he is viewing acceleration from a generalized stance that is close to a Newtonian position. For Jim, acceleration will occur no matter whether the applied force is of a constant size or increasing. As long as the applied force on an object is larger than any opposing forces the object will accelerate. What cannot be explicitly determined from these comments or the context that they were made in, is what, if any, influence the initial state of the object plays. A probable frame for Jim's perceptions of acceleration is shown in Figure 12.

To this point, but with the possible exception of Jim, all of the students that have taken part in this discussion have agreed that for a moving object to accelerate and continue to accelerate a continuously increasing force must be applied to that object. Considering the lack of objection to this stance by the rest of the students, the vociferous disagreement that Kelly's original suggestion (continuous acceleration of an object can be achieved by applying a constant force) was met with, and the consensual agreement with the class produced concept map (see Figure 1) it appears reasonable that this concept represents the core of an acceleration frame that is acceptable to the majority of the class. Such an acceleration frame would be almost identical with Kelly's frame for a moving object (see Figure 11) but with the default

Figure 12. Jim's Acceleration Frame



values for object type and function, and source of the force becoming unknown quantities.

The set of expectations concerning acceleration that this type of frame engenders is experientially familiar to most if not all of these students. If one is driving a car or riding a bicycle and wishes to accelerate more force must be applied to the driving wheels. If the driver wants the acceleration to continue and/or increase the amount of force supplied must also be increased in a continuous fashion. What this frame represents then is a gut-level appreciation of the variable nature of friction.

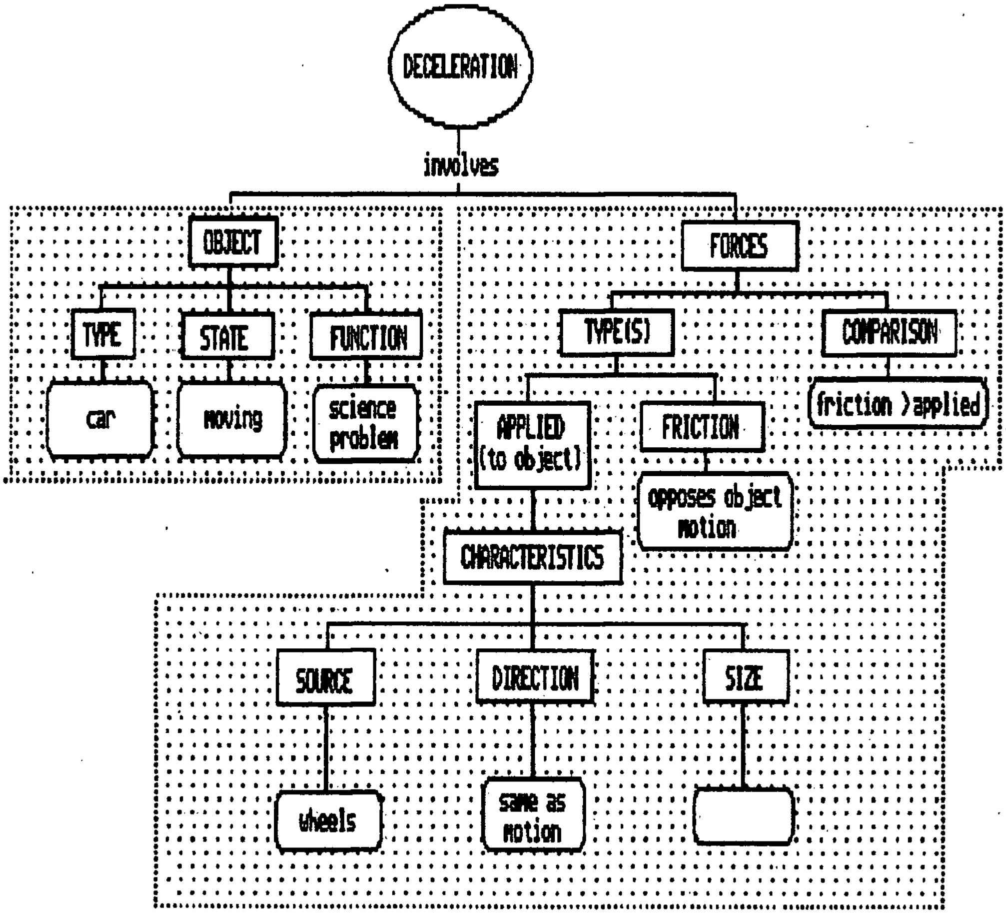
Following the demonstrations the student conceptions of the cause of acceleration appeared to have altered dramatically. The class unanimously agreed that, for these demonstrations, acceleration was caused by the application of a constant force as opposed to the application of a continuously increasing force prior to the demonstrations. On reflection however, this does not appear to be the case. In both demonstrations the object in question was initially motionless. As such, this majority agreement must be restated to include this condition, that is, the acceleration of an initially motionless object was caused by the application of a constant force. Again, this conception of the dynamics of acceleration is almost identical with Kelly's frame for the acceleration of a stationary object (see Figure 10). As a result Kelly's frame, with suitable changes to the default values for object type and source of the applied force, can be viewed as a composite frame for most of the class.

Deceleration

The discussion concerning the dynamics of deceleration was initiated by Kelly. Her view of the cause of deceleration of a moving object was that the forces opposing the motion (in this case friction) had to be larger than the applied forces (see line 5, p. 42, and lines 51 to 53, p. 45). Additional support for this conception of deceleration was provided by Dina (see lines 14 to 17, pp. 42 and 43) and very definitely by Tawnia (see lines 91 to 125, pp. 46 and 47). This conceptualization of deceleration is represented in Figure 13.

Only one other position concerning the causes of deceleration surfaced during the initial discussions. This was provided by Jim. Jim's conceptions of deceleration centre around a need to keep the

Figure 13. Kelly's Deceleration Frame

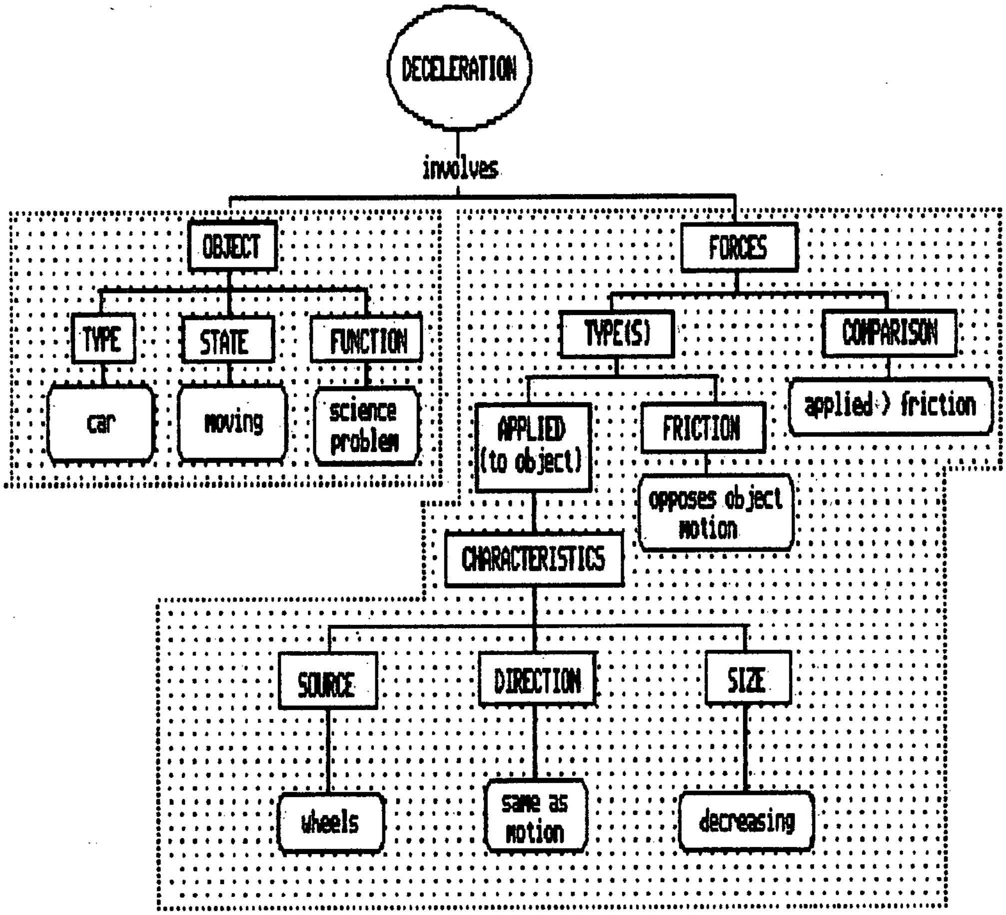


applied, motive force greater than any opposing forces. To reach this state Jim feels that deceleration can be achieved by simply reducing the motive force while still retaining the above condition (see lines 7 to 12, p. 42). This position is also stated by Jody (see lines 28 and 29, p. 44).

Additionally, Jim feels that if the magnitude of the motive force falls below that of the opposing forces the object will stop (see line 19, p. 43). Jim's conceptualization of deceleration is shown in Figure 14.

Jim's comments concerning acceleration indicate that he equates the cause of the motion with the application of a motive force in the

Figure 14. Jim's Deceleration Frame



same direction as the motion. Conversely, if the larger force (in this case friction) operates in the opposite direction to that of the motion the object that is moving must simply stop. As a result of this 'motion implies a force' frame, if the motion of the object is one of slowing down, this can only occur when the motive force is reduced, or reducing, but still larger than the opposing frictional forces. If the frictional forces become greater than the motive force the object must stop.

Interestingly, Jim sees no conflict between his conceptions of acceleration and deceleration. Both of these conceptual sets incorporate, as a core item, the implication that the net force, acting on either an accelerating or decelerating object, is greater than zero and operating in the direction of motion. From a physical point of view, such a force condition can only result in acceleration. For Jim however, the key point is not the net force but rather the default value for the size of the applied force. If an object is accelerating this default value must be either constant or increasing. If an object is decelerating this default value must be decreasing.

In comparison then, the major difference between the frame being used by Kelly to interpret the deceleration of objects and that being employed by Jim lies in the default value for their particular conception of the comparison of the forces involved. Kelly's conception of this comparison dictates that the total value of any applied forces must be less than the total value of any frictional forces, whereas Jim's conception of this comparison is exactly the opposite. For Jim deceleration occurs when the applied forces are greater than the frictional forces but are decreasing (or decreased) from a previously higher level.

The hallway demonstration appeared to cement the frame, initially described by Kelly but with changes to the default values describing the object (an equipment trolley), in place as the interpretational structure of choice for the majority of students (see Figure 15). Although the acceptance of this frame appeared to indicate that the students had opted for a close approximation to the Newtonian model of deceleration (deceleration is a result of a net force operating in a direction opposite to that of the motion) subsequent data collected from the baseball problem suggested that this frame was, in reality, a

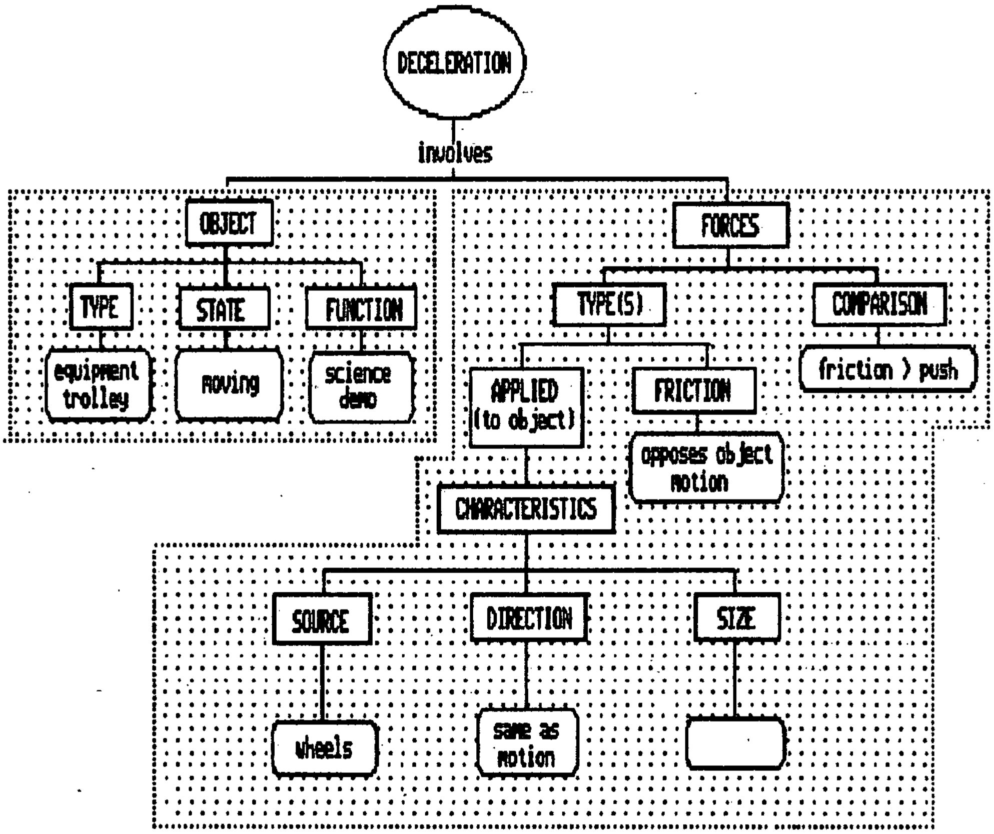


Figure 15. Composite Deceleration Frame Derived From Hallway Demonstration

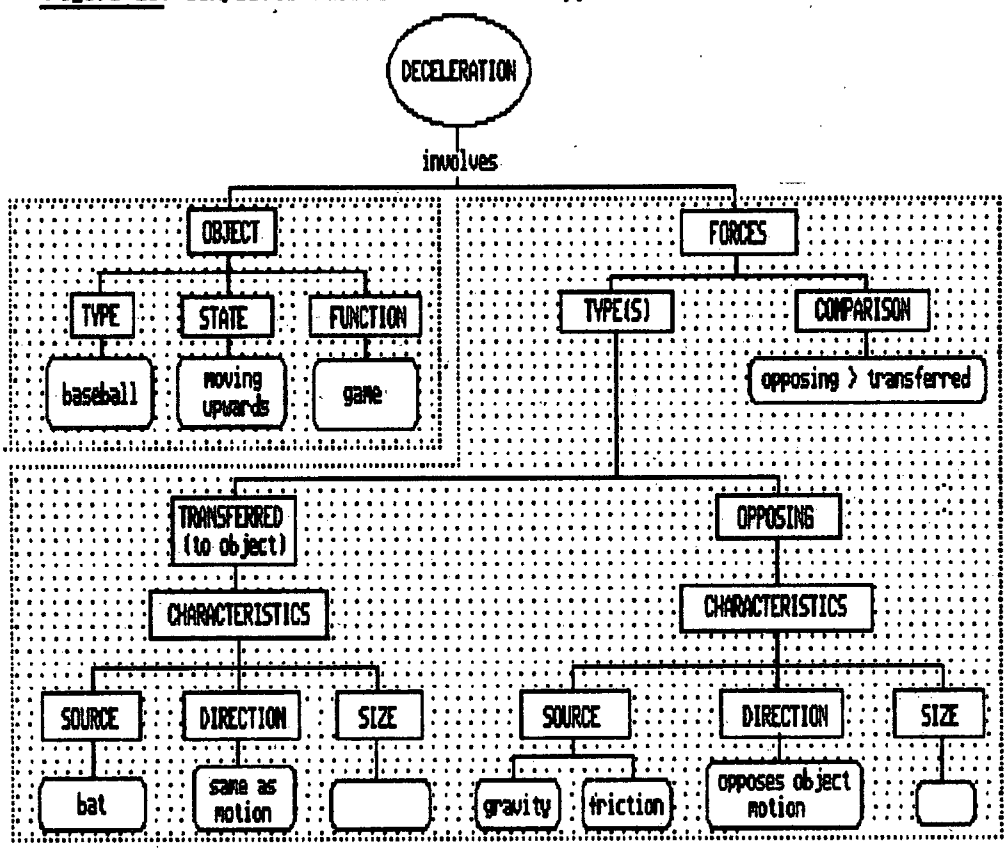
frame that could be used to support the 'motion implies a force' set of conceptualizations.

During the discussion of the baseball problem it soon became apparent that a majority of students (taking part in the discussion) had extreme difficulty with the idea that a ball could move upwards without a force (applied in the direction of motion) to move it upwards. Throughout the discussions (contained on pages 51 to 57) student after student either explicitly states or implies that there must be a transferred force (from the bat) on the ball that keeps it moving upwards. Only Brad and Tawnia appear to have accepted the situation that an object can move, albeit decelerate, without the application of some type of force in direction of the motion (see lines 57 through 59, p. 54, and lines 95 through 106, p. 56).

The concept of 'transferred force' that is so prevalent in these discussions is a necessary condition for these students in order to retain the integrity of their interpretational frames. Up to this point, all the demonstrations and problems that these students have faced have involved some form of easily recognizable motive force directly associated with a moving object. These motive forces have been consistently incorporated into their interpretational frames (as applied forces) and have been one of the major concepts used for their analyses of the dynamics of moving objects. To remove such a major concept from an interpretational frame that has served them well, just because the concept cannot be empirically identified, would destroy the frame. Such a situation is untenable for these students. As a result, that region within their interpretational frames that had once held the concept of 'applied force(s)' must continue to exist. This continued existence is achieved by a metamorphosis of the 'applied force' (from the bat) concept to a 'transferred force' (on the ball) concept with its own set of default values.

In addition to this metamorphosis, that region of the interpretational frame that dealt with the force(s) which opposed motion has had to be expanded to reflect the increased complexity of these forces (see Figure 7). In both of these regions, however, the default value for the size (constant, increasing, or decreasing) of the force (or forces) involved cannot be determined from the transcripts. As such, the default value for the size concept has been left blank. This evolution of the original composite deceleration frame (see Figure 15) into a deceleration frame that supports the type of Impetus Theory that these students appear to be using is shown in Figure 16.

Figure 16. Composite Deceleration Frame Applied to the Baseball Problem



Uniform Motion

The initial discussions of the dynamics of uniform motion were dominated by Brad and Kari. Brad, during these discussions, has put forth the Newtonian position that uniform motion is the result of the application of balanced forces to a moving object (see lines 31 to 33, p. 62, and lines 61 to 63, p. 63). Kari, however, has suggested that the application of balanced forces to a moving object will decelerate and ultimately stop that object (see lines 48 to 51, p. 62). She further suggests that uniform motion can only be achieved with the application of a "decelerating force" (see line 2, p. 61) - a force which is continuously decreasing in size. Kari's conception of uniform motion centers around the requirement for some type of motive force and, as such, can be viewed as a subset of the 'motion implies a force' interpretational frame.

Both of these conceptions of uniform motion have been reconstructed into the interpretational frames shown in Figures 17 and 18. As a result of the general nature of the discussions, however, many of the default values for specific concepts have not been clarified and have been left blank in the frames.

Figure 17. Brad's Frame for Uniform Motion

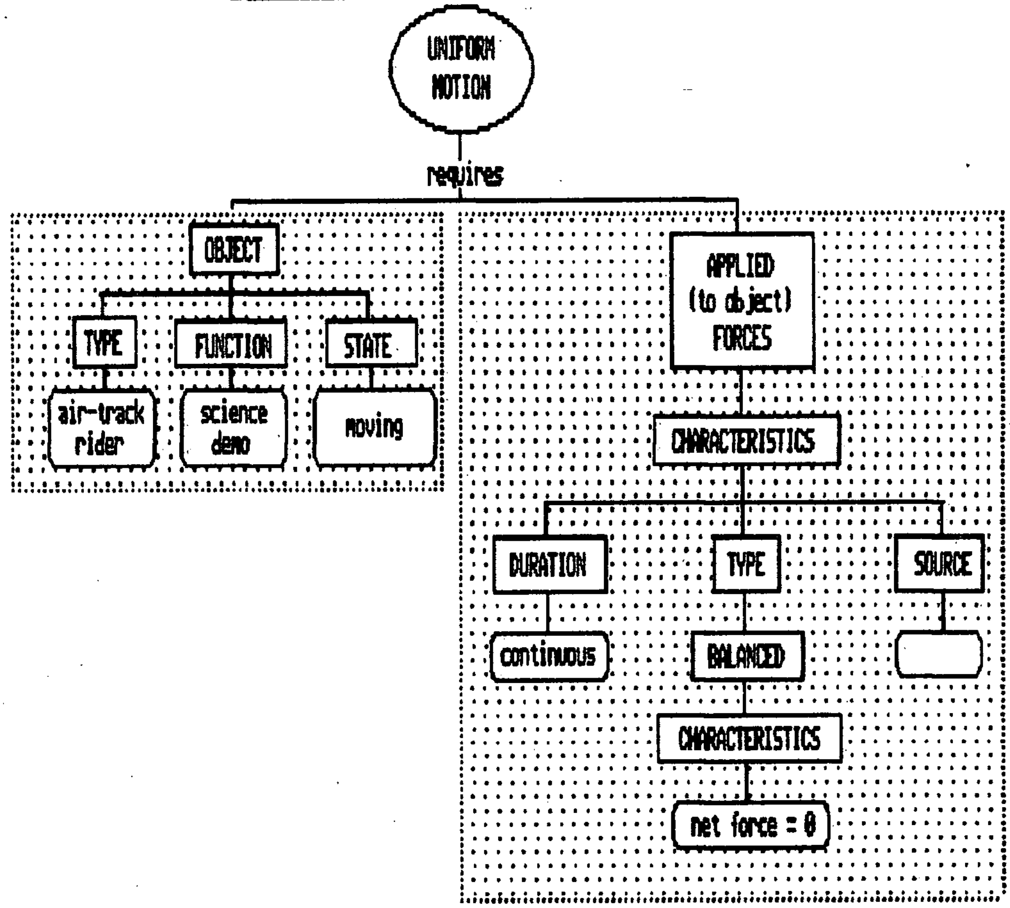
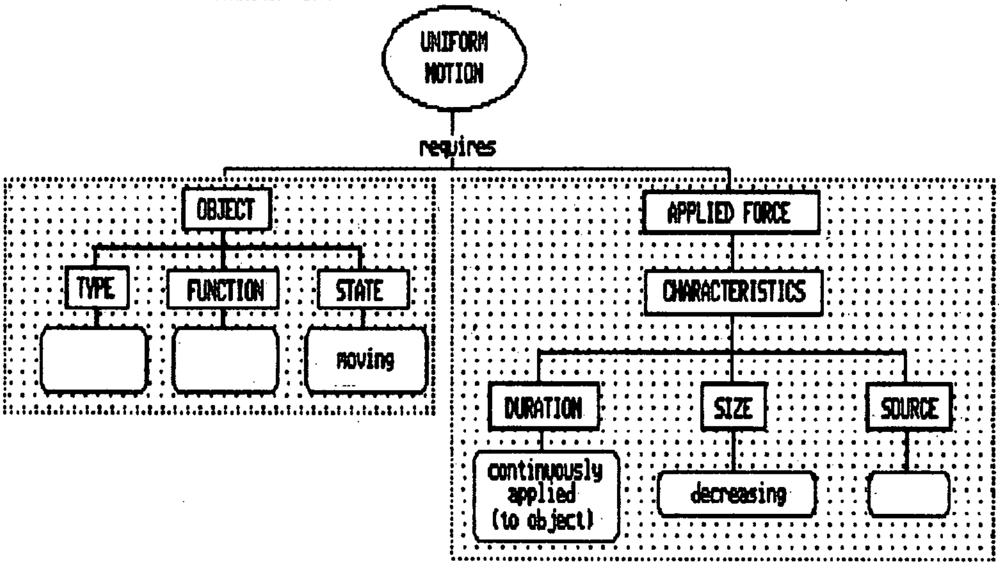


Figure 18. Kari's Frame for Uniform Motion



Kari's conception of the dynamics of uniform motion appears to provide some additional information concerning her previous position on the causes of deceleration (at least as applied to the baseball problem) and which could be applied to the composite frame for deceleration that was applied to the baseball problem (see Figure 16). This conception of deceleration involved a 'transferred force' that operated in the same direction as the motion of the object (see lines 25 to 27, p. 53; lines 108 to 111, p. 56; and line 120, p. 57). What was unclear as far as this conception of deceleration was concerned was the size of the 'transferred force', as such, the default value for this concept was left blank. Both of these conceptions for different types of motion involve the application of some form of motive force, however, Kari has defined the size of the force responsible for uniform motion. The size of this force is continuously decreasing. This suggests that, if Kari is making a distinction between deceleration and uniform motion, the default value for the size of the 'transferred force' should most probably be constant.

Following the demonstration of the effect of balanced forces on a moving equipment trolley, the three students (Heinzy, Steve, and Kari; see lines 64 to 80, p. 64) polled for the description of the type of resultant motion all agreed that the trolley had exhibited uniform motion. This agreement tends to indicate that these students, at least, were either in initial agreement with Brad's interpretational frame for uniform motion or (certainly in Kari's case) were moving towards agreement with this frame.

This was not the case for other students in the class however. Tawnia's and Kirsten's comments (see lines 81 to 94, p. 65) indicate a certain amount of internal confusion on their part. Tawnia's comments appear to be an attempt to obtain a warrant, from the teacher, to validate what she has seen in the preceding demonstration and Brad's interpretation of uniform motion. Tawnia (and probably Kirsten) appears to require that warrant before she is willing to relinquish her interpretational frame of uniform motion (which is apparently similar to Kari's; see line 53, p. 63) and accept Brad's. When this warrant is not forthcoming both Tawnia and Kirsten implicitly declare themselves in favour of Kari's original interpretational frame of uniform motion when they ask the question 'why doesn't the object stop when balanced forces are applied to it?'

The air-track demonstration, which was in place to confront those students that were using some form of a 'motion implies a force' interpretational frame to explain uniform motion, produced mixed results. Without fail, all students who took part in the discussion of this demonstration agreed that the rider travelled with a uniform motion. This point, however, was the only point that could be agreed upon as this demonstration appeared to split the students into at least two groups. One group appeared to interpret this demonstration using a form of Impetus Theory whereas, the other group opted to explain uniform motion using an expanded version of Brad's original interpretational frame (or variants of that frame).

The group of students that appeared to be using a form of Impetus Theory to explain uniform motion included Melanie, Kelly, and Tawnia. For all three of these students, the air-track rider moved because it carried an inherent force. This force has been transferred to the rider when it was given an initial push (see lines 128 to 141, pp. 71 and 72; lines 147 to 160, pp. 72 and 73; and lines 182 and 183, p. 73).

Although all three of these students appear to be using similarly constructed interpretational frames for their analysis of uniform motion (as exhibited by the air-track rider) there are differences in the default values that are being applied to specific concepts within the frame. Melanie's frame, which is assumed to represent the basic structure used by these students (see Figure 19), includes a default value for the transferred force that indicates that it is continually decreasing. Kelly's frame, on the other hand would include a default value for the size of the transferred force that would describe this force as remaining constant. Tawnia's frame, as well, would have the same basic design as Melanie's frame but the default value for the size of the transferred force is unknown. The only information that Tawnia has supplied concerning this default value is that "the net force is going the same way as the direction" (see lines 182 and 183, p. 73). Such a situation involving the air-track rider could be achieved using

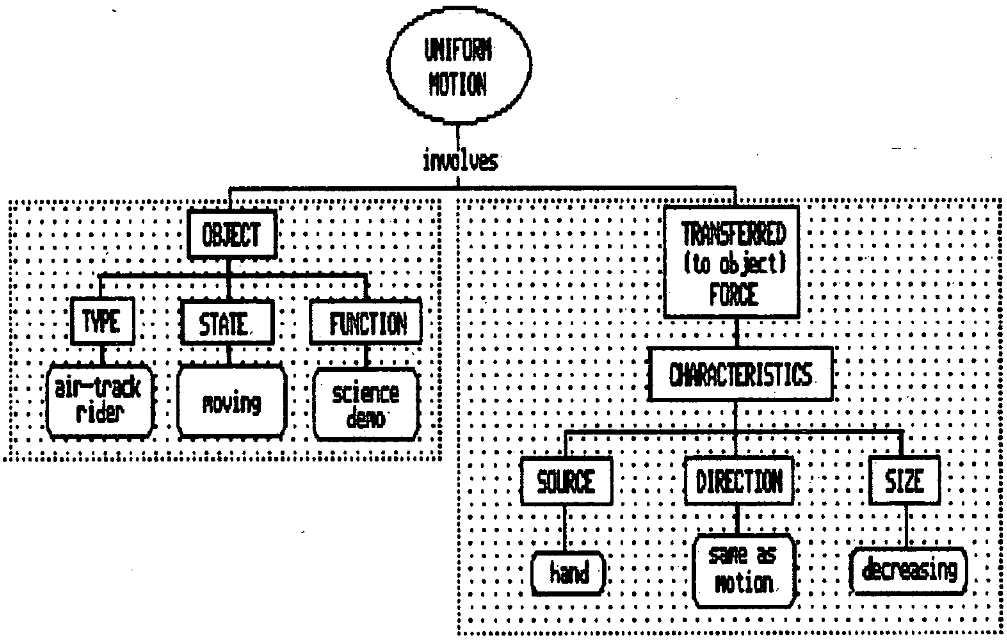


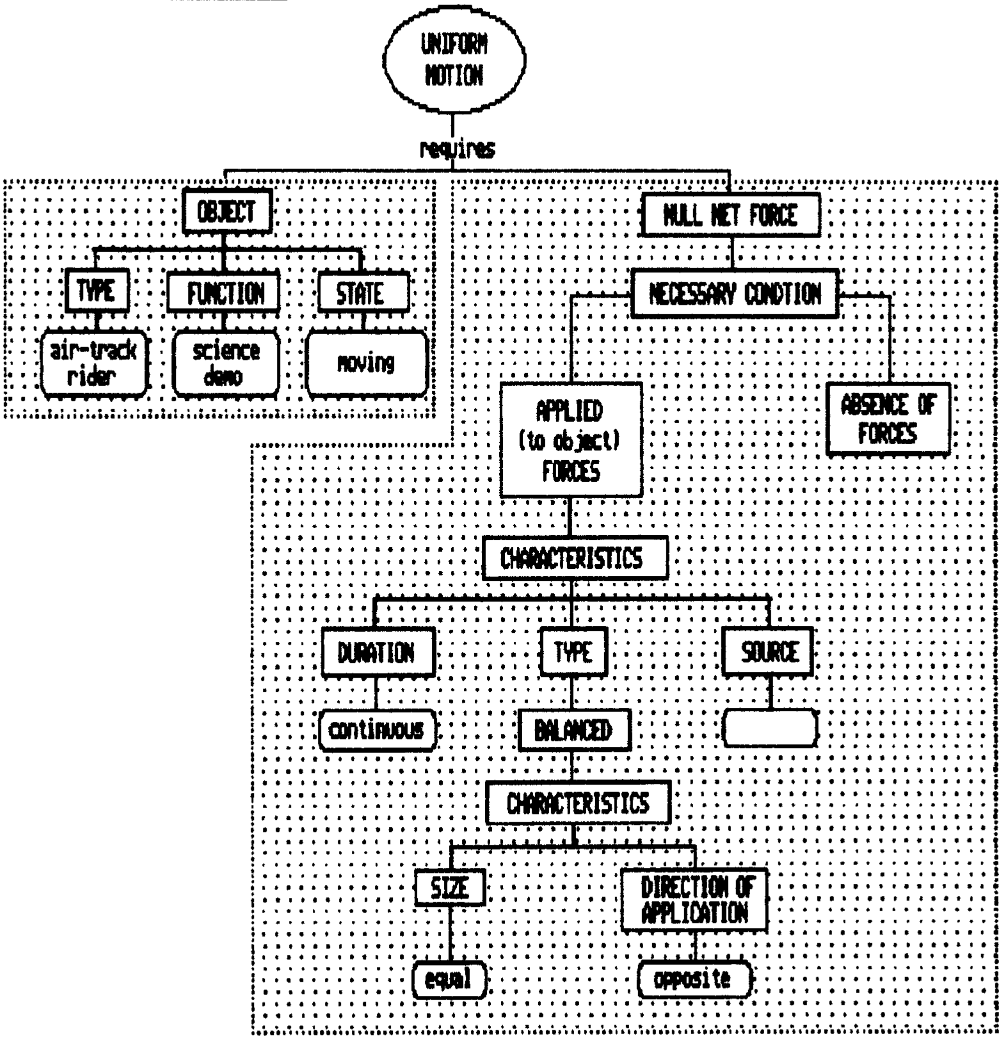
Figure 19. Melanie's Uniform Motion Frame

an increasing, decreasing, or constant value for the size of the transferred force.

Brad, Kari, and to a lesser degree, Heinzy made up the group that appeared to interpreting the motion of the air-track rider using an expanded version of Brad's original frame for uniform motion. In this case, Brad has extended his interpretational frame, that was based on balanced forces, to include the alternative option that uniform motion can be the resultant of the complete absence of forces (see lines 144 and 145, p. 72). By doing so his interpretational frame of uniform motion now represents the general Newtonian position that this type of motion (for an initially moving object) is the result of any force conditions that result in a null net force (see Figure 20).

Kari has also recognized that, for this demonstration of uniform motion, there are no motive forces acting on the rider and that the net force condition must be zero (see lines 199 to 203, p. 74). As a

Figure 20. Brad's Expanded Frame for Uniform Motion

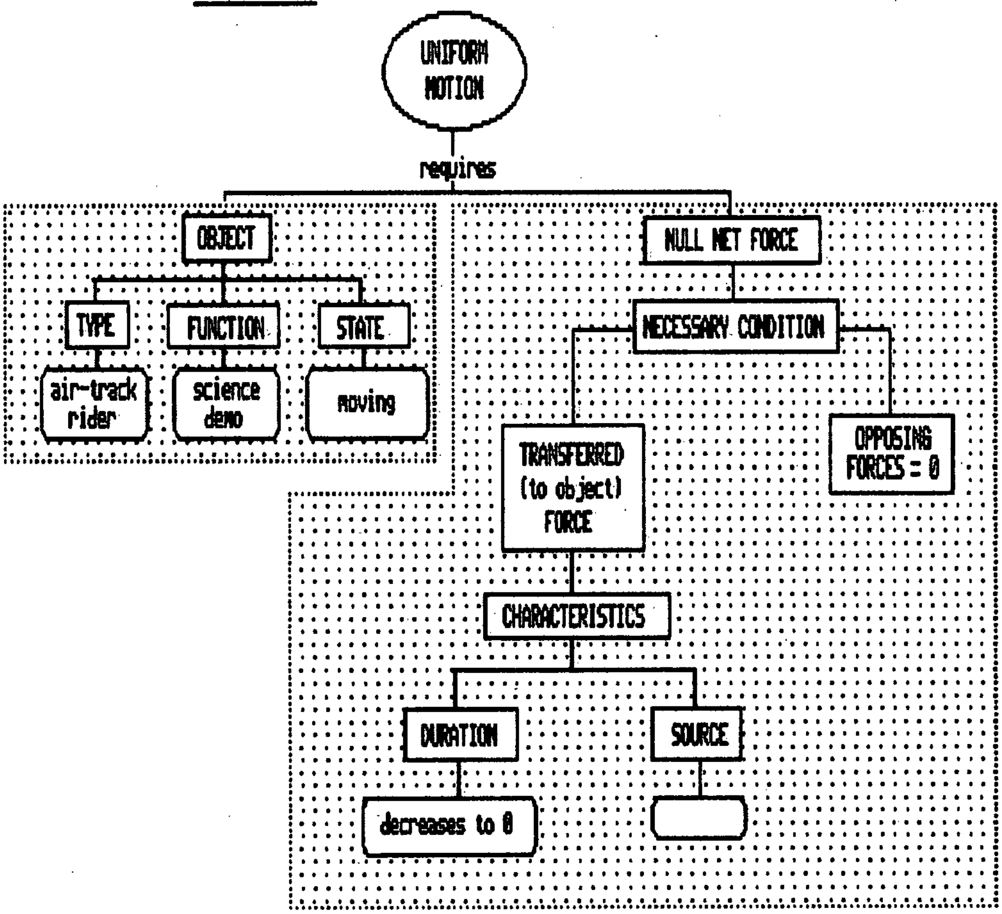


result, she appears to be in complete agreement with Brad's interpretational frame for uniform motion and, apparently, has abandoned her previous frame (see Figure 18) that was based upon the 'motion implies a force' conception.

Heinzy appears to have adopted a compromise position that melds Melanie's 'motion implies a force' conception with Brad's Newtonian position that uniform motion is a result of a null net force condition.

Heinzy feels that there is a force associated with the initial movement of the air-track rider (which, by inference, must be a 'transferred force') but that force quickly falls off to zero. Once the 'transferred force' has reduced to zero he recognizes that there is no longer any force which might accelerate the rider, nor are there any opposing forces which would decelerate the rider (see lines 165 to 173, p. 73). Thus, the rider must be travelling with a uniform motion as a result of a null net force condition. This form of an interpretational frame for uniform motion is shown in Figure 21.

Figure 21. Heinzy's Frame for Uniform Motion



Instructional Strategy Effects on Student Interpretational Frames of Motion

The determination of the effects that the instructional strategy had on the initial conceptions that students were using to explain the dynamics of specific types of motion has been accomplished by comparing their initial interpretational frameworks with those that were constructed after the instructional sequence had been completed. Any effects that have occurred as a result of the instructional strategy can then be recognized as transformations to the type and/or sequencing of concepts within the interpretational framework or to the default values for specific concepts.

Acceleration

The predominant concept concerning acceleration that became apparent during the initial discussions was that a continually increasing force was required to accelerate a moving object. This concept represents the core of Kelly's interpretational frame for the acceleration of a moving object (see Figure 11) and was reiterated by the majority of students taking part in these discussions.

Following the demonstrations and their attendant discussions, this concept had appeared to be dramatically altered, in a majority of students, to correspond with the minimum Newtonian requirement for acceleration i.e. that a moving body can be accelerated by the application of a constant force in the direction of that body's motion. As has already been noted however, the demonstrations that were used involved the acceleration of an initially stationary object and, as such, what these students were describing were their conditions necessary for the acceleration of this type of object. This set of conditions had previously been described by Kelly (see Figure 10) and, if it is assumed that this interpretational frame was a composite frame for the majority of the class, then this frame should not have changed; nor did it. This frame incorporates the minimum Newtonian conditions necessary for the acceleration of a stationary body and should not have changed following the demonstrations because these were designed to illustrate these conditions.

Because there were no demonstrations presented to these students that might have illustrated the minimum Newtonian conditions for the acceleration of an already moving body, it is impossible to make any 'before and after' comparison of the students' initial conception that a continually increasing force is the minimum requirement for the acceleration of a moving object.

Deceleration

The initial discussions concerning the causes of dynamics pinpointed two conflicting interpretational frames among the students. One frame, outlined by Kelly (see Figure 13), illustrates the Newtonian position that deceleration is the result of the net force (indicated by the default value for the 'comparison' concept) on a moving object acting in the opposite direction to the motion of the object. The other frame, outlined by Jim (see Figure 14), adopts a 'motion implies a force' conceptualization of deceleration. In this case, an object decelerates because it's motive force is decreasing in size. The net force (again indicated by the default value for the 'comparison' concept), however, continues to act in the direction of the object's motion.

To begin with, both of these interpretational frames found supporters within the class. Following the demonstrations however,the majority of students appeared to agree with Kelly's interpretational framework for deceleration. As such, the instructional strategy appeared to have the desired effect of convincing the students that the Newtonian frame for deceleration was the more powerful interpretational model of the two frames initially recognized.

It should be noted at this point that the instructional strategy was not entirely successful in that it failed to convince Jim that he should move away from his 'motion implies a force' interpretational frame. As a result of the strategy, Jim did make modifications to his frame in that he did agree that a net force acting in the opposite direction to an object's motion would cause deceleration. However, he also felt that the deceleration would ultimately stop and the object would continue to move forwards with a uniform motion (see lines 8 to 19, p. 49).

The baseball problem, however, has pointed out the limitations of the instructional strategy. All the demonstrations in this instructional sequence involved the application of a motive force to an object. As a result, the interpretational frames that were generated by these demonstrations always involved some form of applied force to the object. The baseball problem, however, did not involve any form of motive force and it soon became apparent during the discussion of this problem that a majority of students in this class were incapable of imagining motion without some form of motive force. Thus they felt it necessary to invent a 'transferred force' that was responsible for the motion of the ball and incorporate this invention into their interpretational frame that described the dynamics of the deceleration of the ball. Because there were no demonstrations involved in this instructional sequence that would explicitly confront the conception of 'transferred force', it is not possible to determine whether the instructional strategy might have had any effect on this type of interpretational frame.

Uniform Motion

The initial discussions concerning the dynamics of uniform motion uncovered two interpretational frames that were being used to describe this type of motion. Brad's frame (see Figure 17) describes the Newtonian conception that uniform motion is the result of the application of balanced forces to an already moving object. Kari's frame, however, appears to based on elements of the 'motion implies a force' conception. In this case, Kari appears to believe that acceleration of a moving object is caused by the application of a continually increasing force, that deceleration of an object is achieved by applying a constant force to that object which is smaller than the total of any opposing forces, and that uniform motion is the result of the application of a decreasing force to a moving object.

Following the first demonstration involving the equipment trolley Kari's interpretation of the dynamics of uniform motion appears to have changed. She explicitly agrees that the application of balanced forces to the moving equipment trolley has resulted in the trolley travelling with a uniform motion (see line 80, p. 64). As such, she now appears to be in agreement with Brad's original interpretational frame and has moved away from her own 'motion implies a force' based frame.

Such was not the case with other students in the class however. Tawnia's and Kirsten's comments (see lines 81 to 94, p. 65) suggest that, although this demonstration has probably raised doubts concerning their own personal, interpretational frames for uniform motion, it certainly hasn't transformed these frames into ones that incorporate Newtonian conceptions of uniform motion. This lack of transformation becomes even clearer following the air-track demonstration when Tawnia aligns herself with the 'transferred force' interpretational frame (see Figure 19) that has been tenaciously defended by Melanie and Kelly.

The air-track demonstration and the discussions resulting from it have provided Brad with an opportunity to extend his original, Newtonian-based frame into one that now represents a truly, generalizable frame for uniform motion that is definitely based on Newtonian principles (see Figure 20). In addition, this part of the instructional sequence appears to have confirmed, for Kari, the validity of Brad's interpretational frame. Her final comments (see lines 202 and 203, p. 74) suggest that she has completely abandoned her original interpretational frame based upon the 'motion implies a force' conception and wholeheartedly accepted the description of uniform motion provided by Brad's interpretational frame.

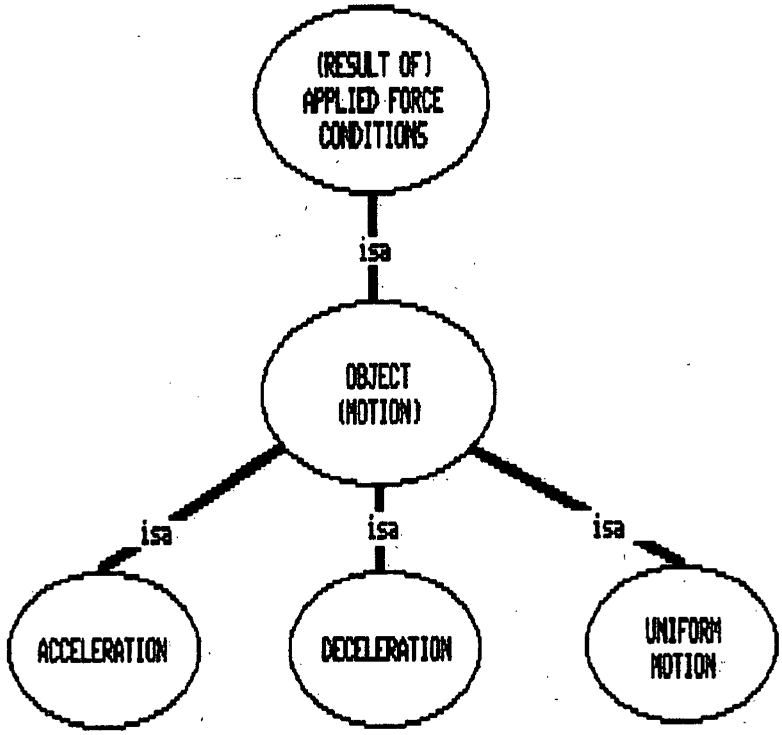
Although the instructional sequence appeared to bring about a successful transformation of Kari's original, interpretational frame for uniform motion, the same cannot be said for Heinzy's interpretational frame. Heinzy's frame (see Figure 21) appears to stake out the middle ground between Melanie's and Brad's interpretational frames by incorporating elements of both of these frames. Due to a lack of a prior interpretational frame (or verbal agreement with a prior frame) that could be used for comparison purposes, it is impossible to determine whether this 'middle ground' frame represents a transitional or final position for Heinzy.

A Summary Analysis of the Major, Student Interpretational Frameworks of Motion

What has become increasingly clear from the preceding analysis is that many students in this class find it extremely difficult to imagine any type of object motion that is not caused by some form of applied force operating in the direction of motion. For a large number of these students acceleration of an already moving object is achieved by applying a motive force which continually increases in size whereas, the acceleration of a stationary object requires only the application of a constant, motive force. Many of these same students also felt that deceleration of an object could occur if, and only if, the applied, motive force was less than the total magnitude of the forces opposing the object motion. At first glance, this conception appears to mirror the Newtonian condition for deceleration which requires that the net force on a moving object operate in the opposite direction to the motion of the object. This condition, however, was unacceptable to these students when a motion event occurred that displayed no explicit motive force. In this type of situation these students found it necessary to invent an applied, motive force that had been transferred to the moving object from some exterior source. Finally, for uniform motion of an object to occur these students felt that some form of applied, motive force was required, and one student suggested that it would have to be decreasing in size. As was the case with deceleration, if an applied force was not explicitly present when an object was travelling with uniform motion, these students felt it necessary to invent a 'transferred force' to account for the motion of the object.

The incorporation of these conceptions of motion into a generalized, interpretational framework of motion has been accomplished by re-ordering the sequence of frames and sub-frames described in the preceding analysis so that they can be connected by 'isa' links. This interpretational framework is shown in Figure 22.

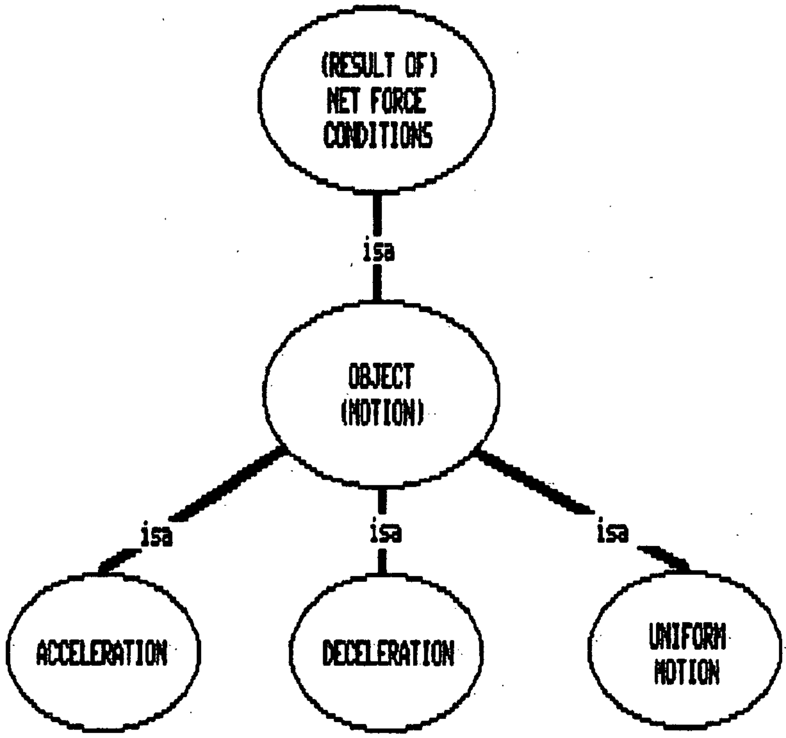
Figure 22. An Interpretational Framework of Motion Based Upon the 'Motion Implies a Force' Conception



In this framework, the lower levels include frames for the specific types of motion. Although it has not been investigated within this research, it is conjectured that these frames would contain data that would allow the user to determine which of the three types of motion is being exhibited by the object in question. The middle level of this framework is assumed to be a junction point which provides additional pathways to frames that provide specific information about the object in question. These frames would contain information about the type of object, it's initial state (stationary or moving), whether it can supply an internal motive force or whether it requires an external force for motion, and so on. The upper level, again can be viewed as a junction point that, allows connections to be made with the specific applied, motive force frames depending upon what type of motion is being exhibited by the object. Data within these frames would include such items as the size and duration of the applied force, whether or not the source of this force is internal to the object or external, and whether or not an applied force has been converted into a transferred force.

For comparison purposes a possible Newtonian interpretational framework is shown in Figure 23. All levels of this framework would operate in a similar fashion to their counterparts in the previous interpretational framework. The upper level, however, would allow access to frames describing the net force conditions required for specific motion types. For example, the recognition that an object was accelerating would allow access to a frame that detailed that a positive (in the direction of motion) net force condition was required and how that net force was achieved. Similarly, if deceleration was recognized a negative (opposing object motion) net force frame would be accessed; if uniform motion was recognized a null net force frame would be accessed. On only two occasions were segments of this type of Newtonian, interpretational framework utilized by students. The first occasion occurred during the discussion of the baseball problem when Brad appeared to be using Newtonian principles to analyze the forces operating on the ball and apply this to decelerating motion (see lines 57 to 59, p. 54). The second occasion occurred during the discussion

Figure 23. A Newtonian Interpretational Framework



of uniform motion when both Brad and Kari utilized the concept of null, net force to explain the uniform motion of the air-track rider.

CHAPTER FIVE

Conclusions, Discussion of Results, and Recommendations

Conclusions

The general problem of this research has been to design an instructional model that would explicate students' conceptions of dynamics and, if necessary, transform these conceptions into ones that more closely approximate Newtonian conceptions of dynamics. Included within this general problem were three, specific problems. The first problem was the design of an instructional strategy that would illuminate the conceptions being employed by students to explain the motion of objects and bring about any required transformations. The second problem was the development of an analytical clue structure, based upon a theoretical perspective provided by Frame Theory, which could be used to describe the conceptual structures employed by students to explain object motion and which would serve as a tracking mechanism for any conceptual transformation initiated by the instructional strategy. Finally, the third problem was the implementation of the instructional model, within an operational classroom, in order to determine the model's ability to explicate student conceptions of dynamics and transform these conceptions where required. Conclusions concerning each of these problems will be discussed individually. However, because the conclusions concerning the first two problems are directly related to the efficacy of the instructional model during the implementation phase of this research, the conclusions regarding the implementation of the instructional model will be discussed first.

Conclusions Concerning the Ability of the Instructional Model to Explicate Students' Concepts of Dynamics

The explication of student conceptions of dynamics using the binary process of concept illumination (via a combination of concept mapping and class discussion techniques) and reconstruction of these concepts into frames and frameworks (by employing the clue structure analysis) must be considered to be a success. As a result of this process the following student conceptions of dynamics have been identified:

1. Acceleration of a stationary object is the result of the application of a constant force to that object (see Figure 10).

2. Acceleration of a moving object is the result of the application of a continually, increasing force to that object in the direction of motion of that object (see Figure 11).

3. Deceleration of an object is the result of an imbalance between any applied, motive forces and any other forces that oppose the motion of the object. This imbalance is such that the total of the opposing forces are greater than the total of the applied, motive forces (see Figure 15).

4. Deceleration of an object is the result of applied, motive forces which are decreasing in magnitude, but which are larger than the total of any forces opposing the motion (see Figure 14).

5. Uniform motion of an object is the result of the application of balanced forces to that object (see Figure 19).

6. Uniform motion of an object is the result of the application of a continuously, decreasing, motive force to that object (see Figure 18).

7. Uniform motion of an object is the result of the application of a motive force to an object that decreases to zero (see Figure 21).

8. An applied, motive force must always be present during decelerating and uniform motion. If no applied force can be recognized it is because the original, applied force has been transferred to the moving object. This 'transferred force' is then responsible for the motion in a particular direction (see Figures 16 and 19).

With the exception of point 5, all of these conceptions indicate a prevalent, underlying theme for students' explanations of the motion of objects. This theme is that all motion in a particular direction, be it acceleration, deceleration, or uniform motion, is the result of some type of motive force. This force can either be directly applied to the object or transferred to the object by some other moving object.

Conclusions Concerning the Ability of the Instructional Model to Transform Student Conceptions of Dynamics

The transformation of student conceptions of dynamics, that were either partially or totally at odds with Newtonian conceptions of dynamics, was to occur as a result of the presentation of (assumed) discordant events that could not be satisfactorily explained using these student conceptions. This technique can only be viewed as being marginally successful.

The initial discussions of the causes of acceleration had suggested that, for the majority of students taking part in this discussion, acceleration occurred because a continuously increasing force was being applied to an object. In addition, a number of students also suggested that the application of a constant force to an object would result in that object travelling with a constant velocity. In order to confront these conceptions and transform them into ones more closely approximating the Newtonian view of acceleration, the students were presented with two demonstrations in which stationary objects were uniformly accelerated by the application of a constant force. The result of this presentation, apparently for the majority of students, was incorporation of this concept (acceleration results from the application of a constant force) into these students' conceptual frame for acceleration as the necessary condition for the acceleration of an initially stationary object. This conception then coexisted with the previous conception (acceleration is a result of the application of a continuously increasing force) which then assumed the role of the necessary condition for the acceleration of a moving object (see Figures 10 and 11). Thus, in this instance, the presentation of what were assumed to be discordant events resulted in the incorporation of a desired conception into an already existing and undesirable framework of acceleration, rather than the transformation of the pre-existing framework.

It must be noted here that, at some point (or points) in the instructional sequence, a transformation towards the desired Newtonian, conceptual frame for acceleration did occur. During the construction of the concept map for acceleration and deceleration (see Figure 8) prior to the discussion of uniform motion, a student consensus had been arrived at that now viewed the minimum requirements for acceleration of either a stationary or moving object to be one and the same - the application of a constant force. Just exactly where and why within the instructional sequence this transformation occurred can only be a topic for conjecture. What is known is that this transformation did not occur as a direct result of the acceleration demonstrations that were presented to the students.

The initial student discussions concerning the causes of deceleration of an object suggested that the majority of students already had a conception of deceleration (deceleration is the result of the applied, motive forces being less than the total of the forces opposing the motion) that was, at least, partially congruent with the Newtonian conception of deceleration (deceleration is the result of a negative net force operating on a moving object). Only two students suggested that the cause of deceleration could be otherwise. For these students deceleration was caused by a motive force which was decreasing in size but always remained greater than the total of any forces opposing the motion (see Figure 14).

Again, two demonstrations were presented to the students in order to confront and transform any non-Newtonian conceptions of deceleration. In both demonstrations, an object was decelerated using the minimum, Newtonian condition, a constant force applied in the opposite direction to the object's motion. The result of these demonstrations was only a partial transformation of the non-Newtonian conception of deceleration described above. The student who had originally suggested this cause for deceleration now agreed that deceleration did result when a constant force was applied to an object in the opposite direction to the motion of the object, but he also suggested that the deceleration of the object would degrade into uniform motion.

The initial discussions of the dynamics of uniform motion illuminated one non-Newtonian conception of uniform motion. This conception held, as it's central tenet, that uniform motion was the result of the application of a decreasing, motive force to an object (see Figure 18). Two demonstrations were presented to the students in an attempt to counter this conception, but these met with only minimal success. Only one student (Kari) indicated that she now felt that uniform motion was the result of balanced forces or a null net force. For the other students who held this initial, non-Newtonian conception, the demonstrations were unconvincing and no transformations of their conceptions of uniform motion were apparent.

In summary, the attempt to transform student conceptions of motion using, what were assumed to be, discordant, motion events cannot be considered to have been successful. In only one case (involving uniform motion) was there a successful transformation of non-Newtonian conceptions into Newtonian conceptions. In all other instances, the attempts at transformation resulted in either incorporation of Newtonian concepts into a non-Newtonian conceptual structure (as was the case following the acceleration demonstrations), or a minimal, partial transformation towards Newtonian concepts (as was the case following the deceleration demonstrations), or no change of the original conceptions concerning a particular type of motion (as was the case following the uniform motion demonstrations).

Conclusions Concerning the Design of the Instructional Strategy

The original design of the instructional strategy can only be considered to be flawed in both of it's major elements.

The use of student-produced concept maps as a basis for delineating major student concepts of dynamics, and recognizing any alterations to these concepts as the lesson sequence progressed, produced one of the classroom teachers' worst nightmares - an immense amount of student products that had to be analyzed and assessed before the next lesson could occur. As a result of this situation, the original, design intent of these concept maps shifted to become a basis for the construction of collectively-produced concept maps. The process of negotiation and compromise that was required to produce these collective concept maps of individual force/motion events ultimately led to a loss of detail and richness of conceptual understanding that could be found in individually-produced concept maps. Certainly, the collectively-produced concept maps were successful in outlining student conceptions of force/motion events. In addition, juxtaposition of these maps with teacher-produced, Newtonian maps of the same events was able to produce varied and interesting debate concerning the merits of each map. However, as a result of the unwieldy and time-consuming nature of these concept maps, they were downgraded from their original position within the design of the instructional strategy and replaced by a direct clue structure analysis of student discussions of force/motion events.

As has already been mentioned, the use of what were assumed to be discordant, force/motion events to initiate transformations of student conceptions of these events to conceptions more closely aligned with Newtonian conceptions of the same events met with only minimal success. Whether this was because the students did not recognize these events as being truly discordant, or because the student conceptions are extremely robust and the students are loath to relinquish a set of conceptions that have served them successful in the past are subjects for conjecture.

<u>Conclusions Concerning the Development of the Analytical Clue Structure</u>

The use of Frame Theory as a theoretical perspective for the development of the analytical clue structure has been extremely successful. As has already been mentioned, the clue structure supplanted concept mapping as the analytical lens of choice for the explication of student conceptions of force/motion events and tracking of any changes in these conceptions as the lesson sequence progressed. The use of this clue structure has allowed the placement of student concepts of force/motion events within reasonably cohesive frame structures that have proven to be visually easy to interpret and have allowed comparisons to be made between conceptual structures, used by different students, to interpret the same force/motion event. Additionally, these conceptual frame structures have proven to be sensitive enough to allow tracking of conceptual change, within individual students, that might have occurred as a result of the application of the instructional strategy.

Summary Conclusions Concerning the Efficacy of the Instructional Model

The instructional model has proven to be successful in the explication of student conceptions of dynamics. This model has indicated that, for a majority of students taking an active part in the lessons, any motion was viewed as being the result of the application of some type of motive force. This explication of student conceptions did not occur as a result of the originally intended use of concept mapping techniques which proved to be too cumbersome to be used within the classroom environment. Rather, the successful explication of student conceptions of dynamics was achieved by the application of an analytical clue structure, based on Frame Theory, to transcriptions of student discussions of specific force/motion events and problems.

The instructional model has proven to be only minimally successful in transforming non-Newtonian, student conceptions of dynamics into conceptions that more closely approximate Newtonian principles of dynamics. Attempts at using, what were assumed to be, discordant events to accomplish these transformations have resulted in the incorporation of Newtonian concepts into non-Newtonian conceptual frames with only very little modification to the original, conceptual frame, or very little or no modification to the original, conceptual frame being employed by the student(s). In only one instance, was a major transformation of an original, student, conceptual frame to a Newtonian, conceptual frame recognized. The reasons for the lack of success of this part of the instructional model cannot be determined from the available data and can only be considered as subjects for conjecture.

A Discussion of the Results

The Alternate Framework of Dynamics

It has come as no great surprise to find that the 'motion implies a force' set of conceptions and its corollary Impetus Theory have appeared as the conceptual structure of choice for the interpretation of force/motion events by the majority of students within this class. Numerous other studies that have attempted to delineate students' conceptions of dynamics have also determined that this conceptual structure was present, either in whole or in part, in the groups of students that they were investigating. As a result of the preponderance of evidence that indicates that this conceptual structure is not confined to any single, definable group of students, this set of related conceptions must be considered to be a form of 'conventional wisdom' dynamics that has been arrived at by using a 'common sense' approach to explain and predict the motion of objects that are so much a part of our everyday lives.

This 'common sense' approach to the explanation of moving objects does not ignore friction nor does it abstract friction into a form of force, it simply accepts that friction is always present and must be dealt with. Herein lies the major point of contention between the 'conventional wisdom' dynamics and Newtonian dynamics and one of the probable reasons why the 'motion implies a force' conceptual structure is so robust and resistant to change.

The power of Newtonian dynamics stems from it's ability too explain and predict the motion of objects within both friction-filled and frictionless environments. In order to reach this state, however, Newtonian dynamics treats friction as a form of abstract force because it opposes motion. For many individuals, however, who have only lived within a friction-filled environment and who have difficulty conceiving of a frictionless environment, friction is not a form of force, but rather an impediment to motion that can only be overcome by the application of concrete forces such as pushes and pulls. Thus, motion becomes intimately connected to the application of motive forces and experientially reinforced by day-to-day living on the surface of the Earth. As a result, an extremely cohesive and parsimonious (for the surface of the Earth) conceptual framework evolves around the central tenet that, any time an object moves it is because of the application of these concrete forces.

The cohesiveness and internal consistency of this conceptual framework for motion can be seen in the explanations that have been given, by the students, for the causes of the various types of motion.

1. Acceleration of a moving object is caused by the application of a continually, increasing force in the same direction as the motion of the object.

2. Acceleration of a stationary object (which is apparently a different situation than acceleration of a moving object) is caused by the application of a constant force.

3. Deceleration of a moving object is caused by the application of a constant force in the opposite direction to the motion of the object.

4. Uniform motion is caused by the application of a continually, decreasing force in the direction in the direction of the object's motion.

Thus, all types of motion have their own specific, applied force cause and no cause overlaps with any other cause. This compartmentalization of types of motion and their causes ensures that any possible areas of tension within this framework of motion are reduced and the integrity of the framework is maintained.

In those cases where no definable force can be located as the cause of some object motion it becomes necessary to invent some form of pseudo-force (the 'transferred force') that is directly related to some previously applied, motive force and incorporate this into the existing framework. In this fashion the integrity and utility of the existing framework is maintained and the individual is not faced with the disconcerting realization that this conceptual framework of the dynamics of moving objects could be incorrect and might require, at the very least, a complete restructuring or, at the very worst, a complete replacement of the existing framework with one that is new and untried. This latter option is one that few individuals would choose for it would result in a period of extreme confusion while the individual sought new causes of the motion of objects and then attempted to construct these new causes into a comfortable and workable framework of dynamics.

The consternation and confusion that would result from the restructuring and/or replacement of an existing, experientially-based framework probably accounts for the inability of the instructional strategy to bring about significant transformations in the 'motion implies a force' conceptual framework that was so prevalent in this class. As an example, in those cases where the instructional strategy provided discordant events that suggested that motion could occur without the application of a motive force (as was the case with the baseball problem and the air-track demonstration) the majority of students might have felt that it was preferable to opt for the translation of the necessary (to account for the motion) applied force to a 'transferred force' rather than call their existing conceptual framework into question and accept the consequences that would accompany such an action. It is also possible that these students had already faced situations where objects moved without any definable, motive force and had already made the necessary adjustments to their conceptual frameworks to account for these. If this was the case, what were initially assumed (by the researcher) to be discordant events were, in fact, not viewed at all (by the students) to be discordant because their conceptual framework already contained an explanation (the 'transferred force') for this type of motion. Thus, the protection of the integrity of the existing conceptual framework of dynamics is of paramount importance. Any changes that might be made to this framework will most likely fall into the category of minor modifications or incorporations that do not call into question the validity of the central tenet of this framework - motion implies a force. Major transformations to this conceptual framework of dynamics will not occur as long as the risks associated with retaining this experientially-based framework are less than the risks associated with replacing it with a new and untried framework of dynamics.

The Elements of the Instructional Model

The use of the testing form of the teaching experiment as the basis for determining the efficacy of the elements of the instructional model has indicated that only the analytical clue structure (and the subsequent representation of student conceptions of dynamics as frames and frameworks) can be considered to have been a success in it's original form. The other element in the instructional model, the instructional strategy, has undergone substantial modification during the research process in response to environmental factors within the classroom.

Originally, that part of the instructional strategy that was to be used for the explication of student conceptions of dynamics was to rely heavily on the use of student-produced concept maps to provide the raw data for the clue structure analysis. Additionally, it was hoped that these concept maps would provide an immediate, classroom window on to the type of concepts and the relationships between these concepts that students were using to explain force and motion events. This was not to be the case however, as neither of these two intentions were able to be successfully implemented within the classroom.

As has already been mentioned, the attempted implementation of concept mapping technique to specific force and motion events as a method of providing an initial explication of student concepts of these events produced an immense amount of data. So much so, that the researcher found it impossible to analyze and collate these data for student, concept patterns and/or concept shifts (resulting from discordant events) on a day-to-day basis. Because of this problem, any discussions concerning comparisons between student and Newtonian conceptions of these events had to wait on the completion of the concept map analyses and, as a result, lesson continuity and flow was reduced.

In addition to the data production and analysis problem, a significant number of students within the class were finding it very difficult (and time-consuming) to construct concept maps of specific force and motion events. This difficulty did not stem from a lack of familiarity with concept mapping techniques for these students had been successfully constructing concept maps throughout the school year on such diverse topics as current electricity, chemical bonding, and cellular reproduction. Rather, the root of this problem appeared to lie within the specific nature of the concepts and concept relations that they had to recognize in order to construct a valid map of the events that were being demonstrated. Prior to the dynamics unit, student concept mapping had been directed at generalized conceptual structures such as the comparison and contrasting of ionic and covalent bonding, and asexual and sexual cellular reproduction. However, with the introduction of the dynamics unit they were having to recognize and tease apart very specific concepts concerning the type, size, and direction of forces that were responsible for the motion of an object or, for that matter, whether any forces were indeed responsible for the motion. The difficulty that these students experienced while attempting to sink down to this level of specificity suggests that concept mapping techniques may not be applicable to such isolated events or that the analytic capabilites of these students may not yet be up to the task of recognizing and abstracting these types of specific concepts.

Because of these two problems with student concept mapping, that part of the instructional strategy that dealt with the explication of student conceptions of dynamics was substantially modified. This modification still involved student concept mapping, however these maps were now used as a catalyst to initiate the discussion and construction of a collectively-produced concept map for a specific type of motion. These collectively-produced concept maps were, in turn, used to provoke further class discussion concerning the differences between student and Newtonian conceptions of motion, and the ability of the student conceptual structure to explain the motion of objects displayed during the discordant event demonstrations. The explication and representation of the student conceptions of specific types of motion was then achieved by directly applying the analytical clue structure to the class discussions. Thus, by the end of the unit that part of the instructional strategy that dealt with the explication of student conceptions of motion had evolved into a reasonably consistent sequence of tactics that included:

1. a focus question (e.g. What would cause this object to accelerate?).

2. a demonstration of the specific type of motion followed by a class discussion of the possible causes of the object motion.

3. construction of individual concept maps of the cause(s) of the object motion.

4. construction of a consensual, collective concept map based upon discussion and debate of the merits of individual concept maps.

5. a comparison of the elements of the collective concept map for a particular type of motion with the elements of a Newtonian concept map for that same type of motion.

6. discordant event demonstrations.

7. a discussion/debate of the cause(s) of the particular motion type displayed during the discordant event demonstration. These discussions focussed upon the respective abilities of the student and Newtonian conceptual structures to explain the cause(s) of the particular type of motion.

8. a post hoc clue structure analysis of the class discussions and debates that resulted in the explication of student conceptions of particular types of motion as frames.

Although this tactical sequence appeared to be agreeable to both the students and researcher, inasmuch as it provided a stimulating classroom environment, it did not provide the immediate window on to student conceptions of dynamics that had been hoped for. Rather the researcher had to rely on a gut-level feeling concerning whether or not any particular classroom discussion was providing adequate conceptual data that could be used to construct a frame structure using the post hoc, clue structure analysis. As a result, the effects of the instructional strategy on explicating student conceptions of dynamics and transforming these conceptions could not be determined on a day-to-day basis except on a macroscopic level.

The operation of this modified instructional strategy within the classroom produced few, if any, class management problems. Because of the strategy's heavy reliance on student analysis, discussion and debate, student on-task time, concentration and interest appeared to be significantly higher than that which would have been generated by more transmissive forms of teaching. Additionally, for this researcher, it was gratifying to see that these students were capable of and interested in grappling with the intricacies of their physical world and, in essence, taking a certain amount of ownership in their own education.

Recommendations

The large number of research studies that have identified the 'motion implies a force' conceptual structure as the interpretational model of choice among their subjects for dealing with the dynamics of moving objects suggests that further research into the explication of student conceptions of dynamics would be redundant. As a result of these successes in identifying this major conceptional framework, it is recommended that any future research be directed towards the design of instructional strategies that will directly confront this conceptual framework. At this point it would appear that this research direction could follow two possible paths.

First, the design of the future instructional strategy could assume the same stance as did this research and attempt to replace the 'motion implies a force' conceptual framework with a new conceptual framework that is based upon Newtonian principles of dynamics. To accomplish this replacement, however, it would first be necessary to thoroughly discredit the existing framework, probably through the use of discordant event demonstrations and, as has been indicated by this research, this is not an easy task. Thus, any research that wished to follow this path would have to begin with an additional research problem that dealt with the design and testing of prototype, discordant event demonstrations in order to ensure that they were, in fact, discordant and had the capacity to discredit the 'motion implies a force' framework.

The second research path that could be followed is a purely pragmatic path. This path would accept the premise that, because the existing conceptual framework is experientially based and has explanatory and predictive capabilities that are continually reinforced on a day-to-day basis, replacement of this framework is not possible. As a result of this premise, the best that any instructional strategy could do, over the short term, is the construction of an additional Newtonian framework of motion that would be dedicated to the interpretation and explanation of events that occur within the school environment and which would coexist with the 'motion implies a force' framework. Indeed, if such a construction and coexistence were possible it is distinctly possible that, over the long term, students would recognize the explanatory and predictive power inherent within the Newtonian framework of dynamics and begin to replace the 'motion implies a force' framework with the Newtonian framework internally.

In addition, it is also recommended that as many science teachers as possible be made aware of the structure and characteristics of this conceptual framework that their students are bringing with them to their classrooms and that lines of communication be opened between these teaching professionals and educational researchers. By making science teachers aware of this conceptual framework and its attendant problems, the number of professionals searching for solutions to these problems will be dramatically increased. Consequently, the probability of designing an instructional strategy that is 'classroom operational' will also be increased. The opening of lines of communication between these two groups should ensure that any instructional strategies designed by teachers and which appear to be successful in confronting the 'motion implies a force' framework would be fully documented and receive the rigorous testing required by the academic community.

Finally, the successful representation of the alternate framework of dynamics using a clue structure analysis based on the theoretical perspective of frame theory suggests that this form of analysis and visual representation should have an equally successful application in those areas of the physical sciences in which students appear to have constructed other specific, alternate frameworks. To this end, it is recommended that additional research be conducted into the feasibility of using this form of analysis to represent students' possible alternate frameworks in the areas of heat, light, and electricity.

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Appendix

Student Problem Sheets

A FEW QUESTIONS ON ACCELERATION

1. The driver, in the car pictured below, has an extremely heavy, right foot. As a result, the accelerator pedal is pressed to the metal and the car is speeding up.

   (a) Draw all the forces acting on this car that are parallel to the direction of motion.

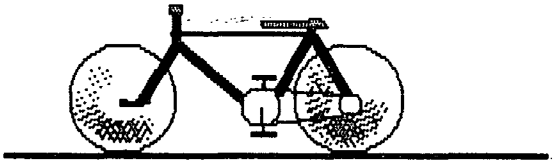
   (b) In which direction is the net force (on this car) operating?

   (c) In one word, describe the forces acting on this car.

2. A boy is riding a mountain bike along a level street. He is applying and equal and constant force to each pedal so that, in total, the force applied by the rear wheel on the road is greater than the force of friction (both air and rolling friction).

   (a) Will this boy be accelerating, decelerating, or travelling with a constant speed. Provide some evidence that will support your answer.

(b) On the diagram below, draw the forces that are operating on this bike (and which are parallel to the direction of motion), and the direction of of the net force.



3. If acceleration is a result of applying a continuous, constant force to an object, why is it that when you are travelling in a car with a constant speed of 100 km/h, on a flat stretch of highway, you must keep your foot on the accelerator pedal?

A FEW QUESTIONS ON DECELERATION

1. The driver, in the car pictured below, has outfitted his car with a radar detector which, at this very moment, is indicating that the car has just entered a police radar beam. Because he was travelling at a constant speed of 120 km/h and does not want to receive a speeding ticket, the driver has removed his right foot (that's right, the heavy one) from the gas pedal and is using it to brake rather heavily.

   (a) Draw all the forces acting on this car that are parallel to the direction of motion.

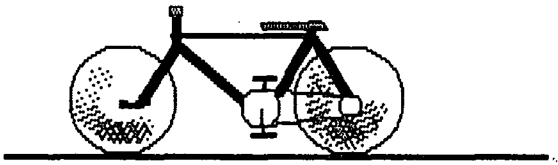
   (b) In which direction is the net force (on this car) operating?

   (c) In one word, describe the forces acting on this car.

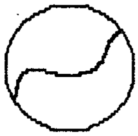
2. A boy is riding a mountain bike along a level street. At present he is not applying any force to the pedals and is just coasting.

   (a) Will this boy be accelerating, decelerating, or travelling with a constant speed. Provide some evidence that will support your answer.

(b) On the diagram below, draw the forces that are operating on this bike (and which are parallel to the direction of motion), and the direction of the net force.

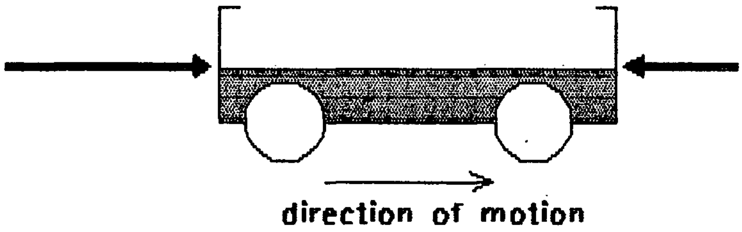


3. A baseball player has just hit a foul ball. The ball is travelling vertically upwards. On the diagram below, draw the force (or forces) that are acting on the ball and which are parallel to the direction of motion. In addition, describe how the ball is moving i.e. is it accelerating, decelerating, or travelling with a constant speed?



ACCELERATION AND DECELERATION - IS THERE A DIFFERENCE?

1. Below is a diagram of one of the carts that we used in the lab to investigate acceleration and deceleration. This cart is moving from left to right and has two forces acting on it. The largest force is on the left side and the smallest force is on the right side.



(a) In which direction is the net force acting in?

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(b) Is this cart accelerating or decelerating? Give a reason (or reasons) to support your answer.

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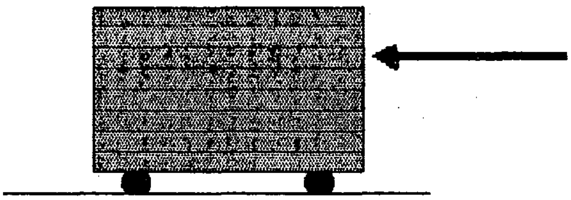
2. Below is a diagram of one of the large trolleys that we were using during the demonstrations. This cart is accelerating from right to left as a result of the force that is being applied to it. Complete this diagram by drawing another force arrow (or force arrows) on it that would slow down (decelerate) the cart.
Below the diagram, explain your reasons for completing the drawing as you did.

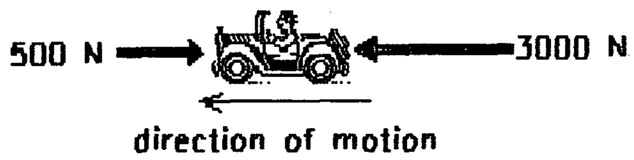


Describe the forces acting on this cart.

3. A car starts from a rest position (i.e. not moving) and is accelerated to 100 km/h and then is held at 100 km/h. At what points in this sequence of events are the forces on the car in balance.

4. If you doubled the net force acting on an object, how would its acceleration be affected.

5. Below is a force diagram of a car. Use this diagram to answer the following questions.



(a) What is the net force acting on this car (please show all your calculations).

(b) What type of motion will the car exhibit?

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6. Below is a diagram of a car that is moving forwards but decelerating. Assume that the only forces acting on car are (a) the force of the wheels on the road that is moving the car forward, and (b) the frictional force between the wheels and the road surface. Draw force arrows on this car that will account for its deceleration. Make sure that you indicate the initial direction of motion of the car.

7. If the unbalanced force on an object is doubled, how will the acceleration of the object be affected?

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8. If the net force on an object is kept constant and the mass of an object is doubled, who will the acceleration of the object be affected?

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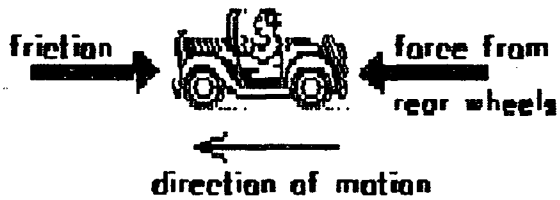
9. Two boys have skipped their afternoon Science class to go to a baseball game. While at the game, one of the boys tells the other that the the ball actually acclerates after it leaves the pitcher's hand and then begins to decelerate as it approaches the batter. He says this occurs because the pitcher gives the ball some force (when he throws it) causing the ball to accelerate. As the force is used up the ball begins to slow down.

The other boy says this is impossible and suggests that his friend has the intelligence of a small soap dish. He says that the ball begins to slow down as soon as it leaves the pitcher's hand because the only force acting on the ball after this point is fluid friction (from the air) which is acting in the opposite direction to the ball's motion.

Which of the two boys do you agree with and why do you agree with him?

A FEW QUESTIONS DEALING WITH UNIFORM MOTION

1. Guess who's back? You're right - its our street version of Mario Andretti. This time however, he's dragging a few speeding tickets with him and, as a result, has changed his driving habits. Analyze the forces acting on his car and



(a) in one word, describe the forces acting on the car.

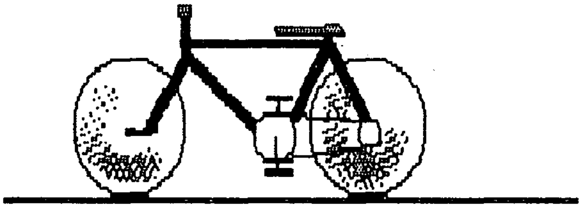
(b) determine the net force acting on the car.

(c) describe the type of motion that the car is exhibiting.

2. A boy is riding a mountain bike along a level street. He is applying an equal and constant force to each pedal so that, in total, the force applied by the rear wheel on the road is equal to the force of friction (both air and rolling friction).

(a) Will this boy be accelerating, decelerating, or travelling with a constant velocity. Provide evidence to support your answer.

(b) On the diagram below, draw the forces that are operating on this bike (and which are parallel to the direction of motion), and the direction of the net force (if there is no net force state this).



3. Captain Kirk and the crew of the USS Enterprise have been ordered to proceed to the planetary system of the star Rigel 4 to investigate an outbreak of tribbles. However, 50 light years from Earth and while travelling at warp factor 5, the ship's lithium crystals implode causing an immedioate shutdown of all engines.

(a) Keeping in mind that there is no friction of any kind in space

(i) will the USS Enterprise (and its crew) be accelerating, decelerating, or travelling with a constant velocity 10 seconds after the engines have been shut down. Provide evidence to support your answer.

(ii) Give your best estimate of fast the ship will be travelling 10 seconds after the engines have been shut down.

(b) Will Captain Kirk and his crew ever be able to reach Rigel 4 and keep their date with the tribbles or are they destined to become a derelict ghost ship forever lost in deep space? Explain your answer.

(c) Normally it would take the USS Enterprise 3 weeks (from the position where the lithium crystals imploded)to reach Rigel 4 if they were able to maintain a constant velocity of warp factor 4. If you think that they can still reach Rigel 4 without their engines, what is your best estimate as to how long it take them. Explain how you arrived at this estimate.