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USE OF COLLABORATIVE COMPUTER SIMULATION ACTIVITIES BY HIGH SCHOOL SCIENCE STUDENTS LEARNING RELATIVE MOTION

A Dissertation Presented

by

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ABSTRACT

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Galileo's contemporaries as well as today's students have difficulty understanding relative motion. It is hypothesized that construction of visual models, resolution of these visual models with numeric models, and, in many cases, rejection of epistemological commitments such as the belief in one "true" velocity, are necessary for students to form integrated mental models of relative motion events.

To investigate students' relative motion problem solving, high school science students were videotaped in classroom and laboratory settings as they performed collaborative predict-observe-explain activities with relative motion computer simulations. The activities were designed to facilitate conceptual change by challenging common alternative conceptions. Half of the students interacted with simulations that provided animated feedback; the other half received numeric feedback. Learning, as measured by a diagnostic test, occurred following both conditions. There was no statistically significant difference between groups on the measure.

It is hypothesized that students did not show statistically significant performance differences on the relative motion test because a) many students were able to solve numeric problems through algorithm use; b) many numeric condition students were aided in their ability to visualize problems by interaction with the treatment; and c) the animation condition fostered little learning because the activities were too easy for students to perform.

Students' problem solving was examined through analyses of protocols and through statistical analyses of written responses. Evidence supported the following findings:

- Numeric condition students had more difficulty with the computer activities than animation condition students.
- Many students in both groups were able to construct accurate mental models of relative motion events.
- A number of numeric condition students used faulty mechanical algorithms to solve problems.
- A number of animation condition students used visualization to solve problems, mapping dynamic visual features of the animations onto posttest problems.

Thus, there is evidence that presentation of numeric data can foster students' use of mechanical algorithms. Presentation of animations can foster visualization of target problems solved off-line. These results suggest that, in addition to the structure of the simulations, how computer simulations are used may have a great impact on students' cognition.

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INTRODUCTION AND LITERATURE REVIEWS

Introduction

Despite the application of resources and the efforts of educational professionals, students often cannot understand seemingly straightforward science concepts. (See Scott, Asoko & Driver, 1991; McDermott, 1982, 1984 for reviews.) There is some consensus that in order for students to develop scientific understanding of many science topics, their naive understanding needs to be modified or abandoned, i.e., conceptual change is necessary (see especially Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1992). One difficult topic for students is Galilean relativity, or relative motion (Aguirre & Erickson, 1984; Bowden, et al., 1992; Camp, et al., 1994; diSessa, 1993; Hewson, 1984; Inhelder & Piaget, 1958; McCloskey, Washburn, & Felch, 1983; McDermott, 1982; 1984; Metz & Hammer, 1993; Pasne, Ramadas, & Kumar 1994; Saltiel & Malgrange, 1980; Ueno, Arimoto, & Yoshioka, 1992; Ueno, 1993; Walsh, et al., 1993; Zietsman & Hewson, 1986).

As a tool to facilitate conceptual change, computers seem promising. Indeed, computer hardware and software manufacturers and academic researchers have heralded the computer as a tool for assisting students' understanding of mathematics and science (See, for instance, Adams & diSessa, 1991; BBN, 1992; Choi & Gennaro, 1987; de Jong, 1991; Driver & Twigger, 1993; Gorsky & Finegold, 1992; Hawkins & Pea, 1987; Hewson, 1984; Holliday & McGuire, 1992; Howe, Tolmie, Anderson, &

Mackenzie, 1992; Kozma, 1991; Lewis, Stern, & Linn, 1993; McDermott, 1990; Njoo & de Jong, 1993; Papert, 1980, 1993; Reiner, Pea, & Schulman, in press; Rieber, 1990; 1991; Roth, 1995; Sachter, 1990; Sherin, diSessa, & Hammer, 1993; Simmons & Lunetta, 1993; Steed, 1992; Stewart, Hafner, Johnson, & Finkel, 1992; Thornton & Sokoloff, 1990; van Berkum & de Jong, 1991; Weller, 1995; White, 1993; White & Frederiksen, 1987; Zietsman & Hewson, 1986). Concerning animated computer simulations, Rieber (1990) concluded that

> The results of this study indicated certain conditions under which animation can be used effectively to elaborate a lesson's content. These conditions include:
> (a) using animation to teach lesson material that requires students to visualize motion and trajectory attributes;
> (b) using animation to teach lesson material that is adequately challenging but not unreasonably so;
> (c) effectively cueing students' attention to motion and trajectory details contained in animation; and
> (d) effectively using animation in tandem with other supportive instructional activities such as practice. (p. 139)

To date, however, few studies have addressed how students learn (or don't learn) science during and after use of computer simulations.

In this study, I investigated interactions between high school science students and relative motion computer simulation activities. Through a combination of qualitative and quantitative methodologies, performance gains on a measure of relative motion understanding as well as changes in understanding and factors associated with the changes in understanding were examined. Goals of the research included improved understanding of methods for teaching relative motion and improved understanding of how computer simulation activities can assist conceptual change. In the broader sense, results of the study have the potential to inform science pedagogy and the design and implementation of computer simulation learning environments. Below, reviews of relevant research are presented to situate the studies conducted.

Literature Review: Research on Conceptual Change

Theories of Conceptual Change

Theories concerning alternative conceptions appear to fall into two varieties (See Vosniadou & Brewer, 1992). On the one hand, theorists like diSessa (1988), McDermott (1984), and Ueno (1993) posit that students' conceptions are not organized. Other theorists, like Carey (1985, 1986), Clement (1982), Strike, Posner, Hewson, and Gertzog (Strike & Posner, 1992; Posner, Strike, Hewson, & Gertzog, 1982), Vosniadou and Brewer (1992) contend that alternative conceptions are indeed like theories.

In Posner et al.'s (1982) oft cited seminal work, conditions believed to be necessary for conceptual change were defined. By conceptual change, the authors were referring to accommodation in which new structures are created to accommodate new knowledge, as opposed to assimilation in which existing structures are used to organize new knowledge. The authors indicated that in order for conceptual change to occur, the student must be dissatisfied with his or her conception. Additionally, the new conception must be intelligible, plausible, and fruitful. The authors likened a student's conceptual change to a paradigm shift in a scientific community (see

T. Kuhn, 1970). The existence of anomaly and the student's "fundamental assumptions about science and knowledge" are considered to be critical components of a student's "conceptual ecology," or set of existing concepts. (See Hulland & Munby, 1994 for a case study contrasting two students' conceptual ecologies.) Posner, et al. (1982) considered analogies and metaphors, along with anomalies, epistemological commitments, metaphysical beliefs and concepts, and other knowledge (including competing concepts) to be elements of the student's conceptual ecology.

In a 1992 paper, Strike and Posner revised the theory of conceptual change to include factors that affect the learner's conceptual ecology. The older theory of conceptual change was considered deficient because, according to the authors, the following factors require consideration:

> 1. A wider range of factors needs to be taken into account in attempting to describe a learners' [sic] conceptual ecology. Motives and goals and the institutional and social sources of them need to be considered.
> 2. Current scientific conceptions and misconceptions are parts of the learner's conceptual ecology. Thus they must be seen in interaction with other components.
> 3. Conceptions and misconceptions can exist in different modes of representation and different degrees of articulateness.
> 4. A developmental view of conceptual ecologies is required.
> 5. An interactionist view of conceptual ecologies is required.
>
> (p. 1)

Indeed, Pintrich, Marx, and Boyle (1993), indicated that affect factors such as the student's opinion of him or herself as able to learn the material, and the goals of the student, affect whether conceptual change will occur. Due to fundamental differences between students and scientists, the authors state that a model which views students' conceptual change as analogous to a scientific paradigm shift (as in T. Kuhn, 1970) is flawed.

Deana Kuhn (1989) stated that it is erroneous to consider children to be scientists because, among other things, children cannot distinguish between evidence and theory. She indicated the tenacity of students in holding onto theories in the face of contradictory evidence. Additionally, she asserted that students will often modify a theory to fit contrary evidence. However, it seems that this is exactly what Thomas Kuhn (1970) says occurs when scientists are confronted with anomalous data. Carey (1985, 1986), who believes that children's alternative conceptions are organized, showed evidence that children display an intuitive theory of biology. Carey (1986) disagreed with McDermott (see 1984), who stated that students "lack a consistent conceptual system at all." (Carey, 1986, p. 1128)

Like McDermott (1984), diSessa (1988) believes that alternative conceptions are not similar to scientific theories but are, rather, constructed of isolated bits of knowledge that are activated in given problem instances. These isolated bits of knowledge, which he calls phenomenological primitives (p-prims) can be applied to diverse phenomena, but lack organization and are applied on a case by case basis.

Dykstra, et al. (1992) indicated that phenomenological primitives were insufficient to account for conceptual change. He believes that it is necessary to determine the conditions necessary for activation of p-prims, including the range of instances in which the p-prims are activated as well as the conditions necessary for application. Additionally, relationships between p-prims and concepts like force and velocity, as well as intra-concept relationships need to be specified in order to account for conceptual change, according to Dykstra, et al. They distinguished three types of conceptual change: differentiation, class extension, and reconceptualization. They believed that "conceptual change does not depend on contradiction, but on disequilibration." (p. 626) Dykstra, et al. distinguished between a situated belief, or applied conception, and a fundamental belief, which elucidates how the world works and is explanatory. This type of fundamental belief seems analogous to diSessa's (1988) p-prims and Brown's (1993) "core intuitions."

Vosniadou and Brewer (1992) believe that children construct mental models with a stable conceptual structure. Vosniadou and Brewer showed evidence of students' construction of "synthetic" models which appear to integrate attributes of the adult "earth is a sphere" theory with children's conceptions such as "the earth is flat." Whether these mental models are stored in long term memory or are constructed spontaneously was an open question. Nevertheless, Vosniadou and Brewer stated that "the fact that 82% of our data can be explained by assuming that the children were consistent in their use of one of a small set of mental models about the earth strongly suggests that there are some stable underlying conceptual structures which constrain the range of possible mental models that children can form." (p. 576) In citing Brewer & Samarapungavan (1991) and Wiser (1988), the authors indicated that:

> The arguments in favor of the position that children are self-contradictory and inconsistent often do not take into consideration that what may appear as contradictory and inconsistent from the adult or expert point of view may not be contradictory from the point of view of the child. (p. 580)

Vosniadou and Brewer stated that for conceptual change to occur, children must reinterpret their presuppositions. This reinterpretation would occur within a different explanatory framework.

Concerning mental models, Collins and Gentner (1987) believe that analogies are used in the construction of mental models. The authors stated: "Our thesis is that people construct generative models by using analogy to map the rules of transition and interaction from known domains into unfamiliar domains." (p. 26) According to Collins and Gentner (1987), the rules that govern transition from one state to another within the model allow inference to occur and allow "simulations" to be performed. Due to the occurrence of specific (erroneous) models, the authors concluded that mental models are culturally transmitted.

Hewson and Hewson (1991), like Dykstra, et al. (1992), indicated that there are different types of conceptual change. They pointed out a distinction between conceptual capture, when students are "learning things they didn't know by making connections to what they already know," and conceptual exchange, in which a student must exchange an existing conception for a competing conception. Hewson and Hewson (1991) indicated that in order for a student to replace one conception with another conception, he or she must show dissatisfaction with the conception.

Driver and Twigger (1993) echoed the views of many of the authors cited above when they stated that "common sense reasoning appears to be governed by more pragmatic principles; it is characterized by ideas which seem to work in particular situations in response to particular tasks." (p.4) In a review of literature, Guzzetti, Snyder, Glass, and Gamas (1993) listed researchers' theories concerning the cause of alternative conceptions:

> Researchers have classified misconceptions as physically derived (resulting from interactions with the physical environment), socially derived (based on interactions with family members, peers, or the media), or instructionally derived (resulting from formal instruction). (p. 117)

In a review of the pertinent educational research published in 1990, Finley, Lawrenz, and Heller (1992) summarized the state of understanding of students' conceptual change:

> This reviewer believes that more in-depth studies of how students' 'common sense' knowledge changes in response to innovative arrangements of instructional content offers one promising avenue for research. If we can describe in some detail exactly what types of transformations of instructional content are made by students as their prior knowledge interacts with instructional content, then we can perhaps move forward and develop theories of conceptual change that will allow us to predict what students will know after instruction. (p. 244-245)

Alternative Conception Classification and Conceptual Change Pedagogy

Selection of the treatment used in teaching studies was dependent on the theory of conceptual change accepted by the researchers. There seems to be some consensus that strategies which promote cognitive conflict will effectively promote theory change. However, as previously indicated, not all researchers believe that students' alternative conceptions are accurately termed theory-like. DiSessa, for example, who believes that students' p-prims are not well organized, appears to be against confrontation and indicated that students need to organize their intuitions, not replace a theory with another theory. Indeed, diSessa (1993) called confrontation "the fallback of all misconceptions research" (p. 201) and stated that "an expert's sense of mechanism is built on a fundamental continuity in form and content with intuitive physics." (p. 201)

In a meta-analysis of statistically based research studies performed in classrooms by science education researchers as well as by reading instruction researchers, Guzzetti, Snyder, Glass and Gamas (1993) concluded that studies which achieved effects all promoted cognitive conflict. Notably, the authors concluded that "nonrefutational expository text (the type of text most commonly found in textbooks)" (p. 130) was ineffective as the sole treatment. Text which promoted cognitive dissonance (such as refutational text, which explicitly refuted misconceptions) were shown to be effective treatments.

Scott, Asoko, and Driver (1991), in a review of conceptual change teaching strategies, organized treatments into strategies that relied upon "cognitive conflict and its resolution" and strategies which are "based upon the development of ideas consistent with the science point of view." In summarizing some of the research studies, Scott, et al. stated:

> Students have variously been encouraged: to exchange their existing ideas for entirely new conceptions (Nussbaum and Novick, 1982); extend or develop existing views and apply them in new situations (Brown and Clement, 1989); develop a scientific understanding which may be held in parallel with existing notions (Niedderer, 1987); recognize the appropriateness and/or applicability of models in different situations (Stavy and Berkovitz, 1980). (p. 327)

As mentioned in Scott, et al.'s review, Stavy (see Stavy, 1991) indicated that conflict strategies may negatively impact some students' self esteem and may cause regression. Stavy (1991), rather than using a conflict strategy, used a strategy which promoted reasoning by analogy. In this study, students benefited from "perceptual reinforcement," in which students experimented with a colored chemical before doing a similar experiment with a colorless chemical. Brown (1993) also advocated use of analogy to refocus students' "core intuitions." He stated that analogy assists with "concretizing" concepts, and providing a physical "explanatory model," as distinct from pedagogical methods that would promote abstract relations. Camp, et al. (1994) employ a "bridging analogies" strategy for ameliorating students' alternative conceptions in mechanics. In this strategy, which was criticized by Fischer (1993) for being based on a transmission model, students are led through a series of analogies which ultimately lead to a target case that was initially conceptualized differently.

Reports by Sequeira and Leite (1991), Dykstra, et al. (1992), and Hewson and Hewson (1991) described techniques that teachers could use to diagnose students' alternative conceptions. Agreeing with Clement (1982) and providing additional evidence that likens students' alternative conceptions to theories (like impetus) previously held by scientists, Sequeira and Leite (1991) contended that teachers should be aware of the history of science in order to anticipate and diagnose students' alternative conceptions. Additionally, Sequeira and Leite promoted making students aware of their alternative conceptions as well as the limitations of the conceptions. They indicated that this should precede presentation of the scientifically held conception.

Dykstra, et al. (1992) promoted the use of conceptual maps as a diagnostic tool which could be used to document interrelationships between concepts as well as indicate the structure of a conception (organizing framework for concepts).

Hewson and Hewson (1991) listed four ways to diagnose the status of a student's conception: "technical interview," non-technical interview, "technical" class discourse, and non-technical class discourse. In a "technical" interview or class discourse, the teacher or investigator uses language consistent with the conceptual change model (CCM). Language is carefully used which assists with the extraction of students' ideas about the plausibility, intelligibility and fruitfulness of a conception. The authors stated that use of language which is not consistent with the CCM model, in an interview or classroom setting, makes the task of diagnosis more difficult, as the teacher or researcher must make more inferences concerning the status of a student's conception. A confounding influence discussed by the authors was students' lack of precision and lack of understanding of the terms "intelligible," "plausible," and "fruitful."

Linn and Songer (1991) indicated that students often hold multiple, contradictory or incongruous intuitions and are apparently unconcerned about the conflict. Students, in thermodynamics, for instance, view heating and cooling as fundamentally different processes. The authors showed gains in junior high school students' understanding of thermodynamic principles through use of a computer simulation (CLP: computer as lab partner) in a predict-observe-explain format. Additionally, the students were exposed to classroom experiences in which a heat flow model was presented rather than a kinetic theory model. The authors posited that such a macroscopic model (heat flow), based on "pragmatic experience" was more easily used by students than the expert kinetic theory. The authors believed that difficult models often cannot be constructed by students and are instead memorized.

Mayer (1989) reviewed several published studies conducted by himself and his colleagues in which students were given a concrete model to examine and concluded that giving students "conceptual" (concrete) models during or before instruction with low aptitude students increased transfer performance as well as conceptual understanding. No gains occurred with higher aptitude students. Domains investigated included physics (radar, Ohm's law, density, cameras, brakes) biology (nitrogen cycle) and computer science (data base and BASIC programming). Norman's (1986) words concerning design of computer interfaces seems applicable to the design of models in general, such as the "concrete models" described in Mayer:

> The problem is to design the system so that, first, it follows a consistent, coherent conceptualization - a design model - and, second, so that the user can develop a mental model of that system - a user model - consistent with the design model. (p.46)

Linder (1993), disagreed with the direction of conceptual change pedagogical research, indicating that more emphasis should be placed on showing students the range of applicability of conceptions. For instance, Linder states that Newtonian mechanics was sufficient to send a man to the moon. In his conclusion, Linder stated:

> I want to argue that science educators' depiction of learning should be extended so that less emphasis is put on efforts to change segments of students' existing repertoires of conceptualizations and more effort on enhancing students' capabilities to distinguish between conceptualizations in a manner appropriate to some specific context--in other words, being able to appreciate the functional appropriateness of one, or more, of their conceptions in a particular context, making science education into a functional base from which to view the world. (p. 298)

Hawkins and Pea (1987) stressed the need for students to become acculturated into the scientific community. They developed software which they claimed fostered students' scientific acculturation. Howe, Tolmie, Anderson, and Mackenzie (1992) showed evidence for conceptual change when a group of students interacted with a computer simulation. They believed that the dynamics of groups can foster conceptual change. Driver, et al. (1994) and Cobb (1994) presented a balance between social constructivism and individual conceptual change. Minstrell (1982) stated the following about classroom interactions and conceptual change:

> The results of my investigation suggest the following instructional factors that apparently aid in the development of the students' concept of force: a) an engaging, free thinking, free speaking social context, in which students are encouraged to articulate their beliefs, b) a juxtaposition of a variety of first-hand experiences with static objects, and c) encouragement to search for the simplest, consistent, rational argument that will explain the similarity of effects in an apparent diversity of experiences. (p. 10)

Though Watson and Konicek published in 1990, their statement concerning the state of conceptual change research is still salient:

> We need to study more deeply the views held by children [and older students], to learn the purposes they serve, to learn their innate structures, and to learn how they are formed and used. Perhaps then we will be better able to understand our role as teachers. (p. 685)

As illustrated in the preceding review, there is disagreement concerning:

- alternative conception diagnosis.
- what is considered to be conceptual change.
- whether students' alternative conceptions are theory-like.
- how students' conceptual change can be facilitated.

Alternative Conception Diagnosis

Concerning diagnosis and classification of students' alternative conceptions, a 1992 Science Education issue that reviewed 1990 science education research, claimed that additional basic research must be done to diagnose students' alternative conceptions.

Research that classifies students' alternative conceptions is, however, time consuming and inexact. Fischer (1993) promotes analysis of videotape to accurately diagnose students' thought processes; he believes that one cannot completely analyze students' responses through analysis of audio tapes or written transcripts. However, though students' protocols do provide useful qualitative data, analysis is dependent on interpretation of students' responses. Hewson and Hewson's (1991) "technical" interview and "technical" classroom discourse show promise; it seems that even by requesting students to use "technical" language in which they express their opinions of whether an idea is plausible, intelligible or fruitful, a teacher may not get an accurate indication of the students' opinion of their own or other conceptions. One reason, as indicated by Hewson and Hewson, is that students are often imprecise in their use of language. Camp, et al.'s (1994) "make sense" scales seem to extract similar information concerning students' opinions of science concepts. Also, new methodologies may assist with diagnosis; Dykstra, et al.'s (1992) research program in which artificial intelligence will be applied to protocol analysis seems promising . Dykstra et al.'s work looks promising due to their commitment to protocol analysis which describes a model of student's thinking which is predictive.

What Is Considered To Be Conceptual Change

Concerning "what counts" as an alternative conception, there appears to be consensus that alternative conceptions are important when they are fundamental beliefs that serve as a framework for a student's reasoning. There is also evidence that students' alternative conceptions tend to be applied on a case by case basis. (This seems consistent with evidence which shows that students tend to classify problems according to surface features instead of according to underlying principles (see Schauble, 1992).) Thus, there is disagreement concerning whether such alternative conceptions are at all like theories. As previously mentioned, diSessa (1988) and McDermott (1984) disagree with the apparently dominant view (see, for example, Clement, 1982; Vosniadou & Brewer, 1992; Carey, 1986, 1985) that students' alternative conceptions are theory-like.

Consistent with the view that students' alternative conceptions tend to be organizing frameworks, conceptual exchange was distinguished from conceptual capture by Hewson and Hewson (1991). However, as diSessa (1988) alludes, such distinctions presume that students must exchange one theory for another theory and not merely organize their conceptions.

<u>Whether Students' Alternative Conceptions Are Theory-Like</u>

Concerning the process of conceptual change, the conceptual change model promoted by Strike, et al. (1992) and Posner, et al. (1982) seems attractive to many who would claim that students' alternative conceptions are theory-like. However, a major criticism of the model, which likened students' conceptual change to the type of changes that occur in a science community during a period of paradigm change (see T. Kuhn, 1970), is that students may not operate like scientists . Specifically, there is concern that students have different goals and opinions of themselves as learners than do scientists (Pintrich, et al., 1993) and may also reason differently than scientists (D. Kuhn, 1991).

<u>How Students' Conceptual Change Can Be Facilitated</u>

DiSessa (1988) believes that novice students need to organize their fundamental conceptions (p-prims); he believes that properly structured experiences within a computer microworld will facilitate such organization of conceptions. Similarly, Papert (1980, 1993) believes in the benefits of students' design and construction enterprises within computer microworlds, what he would term "constructionism."

Notwithstanding the positions of diSessa and Papert, there is some consensus that cognitive conflict must be facilitated for a student to engage in conceptual change. An important caveat is raised by Stavy (1991) however, to pedagogical strategies that promote conflict; namely, that such conflict may be counter-productive for some students. Minstrell's (1982) position, in which classroom discussion is promoted in an environment in which students are not afraid to be wrong, may foster students' conceptual conflict without loss of self-esteem. Additionally, theorists like Champagne & Klopfer and Osborne (as referenced by Hulland & Munby, 1994), indicated that in order for students to make successful use of new knowledge they must have in place the framework necessary to process the information (See also Karmiloff-Smith & Inhelder, 1975). Vygotsky's (1978) idea of the "zone of proximal development" is closely related and involves the difference between competence when solving problems alone and competence when aided by an adult or more accomplished partner.

Conclusion

To summarize, it appears that the conceptual change model (which necessitates that for conceptual change to occur the student must be dissatisfied with the old conception, and must find the new conception intelligible, plausible, and fruitful (see Strike, et al. 1982; Posner & Strike, 1993; Hewson & Hewson, 1991; Hewson, 1984)) is a viable (see von Glasersfeld, 1994) representation of what must occur for students to exchange one conception for another conception. Many pedagogical strategies which promote cognitive conflict show efficacy in facilitating conceptual change, apparently providing the student with a source of dissatisfaction with his or her current conceptions. Additional basic research is needed to efficiently diagnose and classify students' alternative conceptions as well as to develop new pedagogical strategies and refine current strategies which facilitate conceptual change.

Literature Review: Research On Relative Motion Learning

Below, a review of studies which classified students' relative motion reasoning is followed by a review of programs that tested pedagogical strategies for teaching relative motion.

Research Which Classified Subjects' Relative Motion Reasoning

Aguirre and Erickson (1984) attempted to investigate preconceptions of twenty tenth-grade students, eleven male and nine female volunteers, in British Columbia. Males and females gave similar responses. In describing students' protocols, the authors indicated the following:

> The student's response may have: omitted an important variable, used a qualitative rather than a quantitative

description, or failed to recognize the importance of certain procedures such as adopting a common reference point to describe several locations in the same setting. (p. 451)

They describe "inferred rules" that students apply to a range of relative motion problems, but they indicate that these rules are "highly context dependent" (p. 451). They documented both misconceptions and accurate conceptions. Two of the students' accurate conceptions, according to the authors included:

• hypotenuse is smaller than sum of sides (for a two dimensional relative motion case) This is considered significant as it indicates a directional sensitivity on the part of the students.

• forces that act simultaneously are considered to act simultaneously and not serially. (However, some students posit that two forces "fight" with one another) (see p. 452)

Difficulties and misconceptions identified by Aguirre and Erickson (1984) included:

- the use of many reference points in a description of position.
- the use of qualitative descriptions of relative position. (see p. 452)
- the dependence on the river current of the boat's velocity vector relative to the river.

In their research, Walsh, et al. (1992) used a phenomenographic methodology to investigate students' explanatory ideas for relative motion scenarios. The authors established a hierarchy of conceptual frameworks which students used to explain instances of relative motion. The attempt to categorize students' responses in this hierarchical fashion resembled Aguirre and Erikson's 1984 effort.

McCloskey, Washburn, and Felch, in "The straight-down belief and its origin," published in 1983, investigated subjects' relative motion misconceptions concerning the path of a dropped ball. This study involved paper and pencil tests, as well as several laboratory experiments. Throughout, McCloskey, et al. argued that there is reason to believe that students believe that a ball that is dropped by a person will land directly below the spot at which it was dropped. The authors suggested that the straight down belief is part of many people's knowledge system concerning movement. Through analysis of a controlled computer experiment and a controlled video experiment, the authors made a case for the idea that the straight-down misconception is caused by a perceptual illusion. The limitations of smooth pursuit eye movements were suggested to be a contributor to this illusory perception. Below are descriptions and summary results of the experiments conducted by McCloskey, et al.

In the first investigation, 99 university undergraduates (62 physics trained, 37 physics untrained) engaged in a paper and pencil test in which they were given a picture of a walking person who was about to drop a ball. The subjects were instructed to mark where the ball would hit the ground, draw the path the ball would follow, and mark the point where the person's hand was positioned when the ball hit the ground. Forty-nine percent indicated that the dropped ball would land straight down from where it was dropped (62% of those who had never had physics).

Problem two was presented to 47 undergraduates (32 physics trained). In this paper and pencil test, subjects were instructed to draw the path of ball dropped from an airplane, ignoring air resistance. In this study, 36% indicated that the object would fall straight down. Nine of the fifteen physics untrained subjects responded that the ball would fall straight down.

In another study conducted by McCloskey, et al., two related problems were presented. In the first, subjects responded to a paper and pencil test in which a ball was dropped from a conveyor that spanned a canyon. Thirty-one undergraduates (16 physics trained) answered this paper and pencil problem; 23% said it would land directly under the point at which it was dropped (straight-down response). In the second problem associated with this phase of the investigation, 33 (14 physics trained) were asked to indicate where a ball which was dropped from a ramp into a canyon would land. The reported results were striking, especially when compared to responses, made by a similar sample of university students, to the conveyor problem. For the ramp problem, only 6% indicated that it would fall straight down.

McCloskey, et al. attempted to investigate the effects of more concrete problems on the results obtained. In the first of these experiments, two related conditions were presented. In the first, the experimenter dropped a steel ball bearing . In the second, the same ball was rolled down a ramp and off of a filing cabinet. Subjects participating in each of the conditions were instructed to mark on a diagram where the ball would hit. For the walker condition, relative to where the ball was dropped, 51% of the 37 students said the ball would drop straight down. For the ramp condition, 9% of the 32 students said that it would land directly under the point from which it was dropped.

In another experiment, 21 undergraduates (13 physics trained) were instructed to walk toward a target point on the floor and to drop a ball so that it would hit the target. Subjects' intentions were obtained after the attempt. As reported by the author, subjects' intentions seemed consistent with their performance in the drop-to-hit target situation. In their reporting of intentions, 33% intended to drop the ball when their hand was directly over the target. This intention suggested that these subjects employed a straight down assumption.

In actuality, as reported by McCloskey, et al., subjects did not drop the ball where they intended. In experiment 2b, there were two conditions. In the first condition, 20 undergraduates, including thirteen who had previously taken physics, repeated the procedure of the previous experiment (labeled experiment 2a). In the second condition, 10 undergraduates were instructed that they should try to drop the ball when it was directly over the target. However, in experiment 2a, subjects who reported attempting to drop the ball when it was directly over the target, had a mean release point of 10 cm. before the target. Subjects in experiment 2a who reported dropping the ball before the target in order to hit the target dropped the ball an average of 22 cm. before the target. It is curious to see such a disparity in mean release point. It is also interesting to note that between experiments, the percentage of students who intended to drop the ball over the target in the "drop to hit target" condition, varied considerably. Thus, no trend is indicated as to the frequency of occurrence of the "straight-down" belief, by experiments 2a and 2b.

In experiment 3, the subjects were 18 undergraduates . This experiment utilized a CRT display on a DIGITAL pdp-11/20 computer. In this study, the CRT displayed a moving box with a moving dot inside the box during some trials. The CRT displayed the moving dot without the box during other trials. McCloskey, et al. referred to the conditions as the box and no box conditions. The results of the trials indicated that subjects entertained an accurate perception for most cases of the no box condition, and inaccurate perception for all but one case of the box condition (in this case, the dot's velocity relative to the screen exceeded the box's velocity relative to the screen.) Evidence from these trials was used as evidence of a perceptual illusion. (McCloskey, et al., 1983). It does seem that these results may buttress the straight down hypothesis, but the motion shown by the subjects to be the "true" motion was not completely consistent with the straight down instantiation.

In another experiment, 18 of 36 subjects, (undergraduates, graduate students and support staff at Johns Hopkins), viewed videotape of a walking person dropping an orange ball of paper. The other eighteen subjects viewed a videotape of the same ball rolled off a filing cabinet. All of those who viewed the ball roll off the filing cabinets stated that the ball fell forward of the release point. Results were different for those who viewed the ball dropped by a walker. Ten of the eighteen subjects said the ball fell straight down from where it was dropped. Because 10 (56%) judged the ball to fall straight down (even though it did not), when this videotape was viewed, the authors posited that a perceptual illusion is the cause of the straight-down belief. Further data for this hypothesis stems from the fact that four subjects stated, in response to a question about the realism of the videotape, that the video had been faked because the ball needed to be dropped ahead of the target in order for it to hit the target. Three of these subjects reported that the ball went straight down on the video; one said that the ball fell backward.

Halloun and Hestenes (1985) stated that many students' explanations about non-accelerated motion are similar to the impetus theory of motion. Saltiel and Malgrange (1980) and Hewson (1984) indicated that students focus on the cause of non-accelerated motion. Hewson (1984) quoted Clement (1982) as saying that students view a force to be associated with non-accelerated motion.

A salient question is: could it be that some students are confusing the technical use of the word "force" with momentum and the effects of friction (wind resistance and other instantiations) (see McDermott, 1984; diSessa, 1988)? For instance, Halloun and Hestenes (1985) showed that many students feel that a force is necessary to maintain a constant speed. Is not that the case for everyday experiences of motion (e.g., to maintain steady speed in an automobile, a constant force must be applied to overcome friction)?

In studies of students' "common sense beliefs of motion," Halloun and Hestenes (1985), found that most of the college physics students involved in the study confused position, velocity and acceleration. Most of the students also used the medieval idea of impetus to describe the cause of motion. Phrases like the object was "'trained to do something'" (p. 1063) occurred in the protocol. Other students held more Aristotelian notions of the cause of motion. A minority held Newtonian beliefs. Some subjects in Halloun and Hestenes' study displayed the misconception, described by McDermott (1982) and addressed in Hewson's (1984) software treatment, that two objects that are at the same position must be going the same velocity.

As indicated by Saltiel and Malgrange (1980), in everyday speech, the terms "'true motion'" and "'apparent motion'" are used. Rest and motion are seen as very different instances. The idea of a reference frame is foreign. Saltiel and Malgrange indicated that a preferred frame of reference is implicit in day to day life observation of motion. The ground is stated to be the "most common example." (p. 75) Saltiel and Malgrange thus indicated that a velocity is termed to be "proper". It is a property of a body as a result of the cause of the motion. Saltiel and Malgrange indicated that for students the cause of motion is not separated from the motion itself. When the cause is not apparently linked to the motion the motion is regarded to be "apparent" and not real.

That some students have the idea that some motion is not true but is, rather, <u>illusory,</u> was mentioned in Saltiel and Malgrange's paper. Ueno, Arimoto and Yoshika (1992) expressed a similar idea. Saltiel and Malgrange posited existence in the minds of some students of the notion of "proper velocity". Their hypothesis was that, in general, students display a spontaneous way of reasoning which is inconsistent with the reasoning of a physicist. The authors posited students' use of a "natural model" which is in contradiction to a "kinematic model of the physicist". (p. 75)

Findings from an investigation that used fifty first year university students, engaged in paper and pencil tests of qualitative understanding, included the fact that answers given by students are context dependent and that transfer across contexts is often not demonstrated by students. Saltiel and Malgrange found similar reasoning patterns among 11 year olds and among first and fourth year university students.

Saltiel and Malgrange contrasted kinematic explanations with "natural model" explanations. In the "natural model," notably, distance traveled and "proper velocity" were considered to be invariant. Direction of travel was also considered to be invariant. They also discovered that students rarely considered the possibility of using a different reference frame.

Inhelder and Piaget (1958) addressed subjects' difficulty with coordinating two frames of reference. In referring to work published in Piaget's Les Notions de mouvement et de vitesse chez l'enfant, Inhelder and Piaget spoke of tests of subjects' ability to solve relative motion problems. In this research a snail was set on a board. The snail would move from left to right or right to left. The board could also be moved from left to right or right to left. They stated:

> It is not before the level of formal operations that predictions can be made for both sorts of motion simultaneously, for in this case two systems of reference must be coordinated, one of which is mobile and the other immobile. (p.319)

Research That Promoted Or Tested A Relative Motion Pedagogical Strategy

Metz and Hammer explored students' problem assessment and response to computer feedback in a recent paper (Metz & Hammer, 1993). In this research, eleven students entering the ninth grade and one student entering the twelfth grade were involved. Seven were female, five were male. The subjects were participants in a summer enrichment program. Each subject (with the exception of one) solved eleven relative motion puzzles in an hour interview. During the interview, students engaged in a "think aloud" process where they were encouraged to explain their reasoning process and to make sense of the motion displayed, subsequent to each prediction, by the computer simulation. After a student gave a prediction about the expected result of the motion of a frame of reference and an object that moved within the frame, the situation was simulated on a Sun workstation computer running Elmira, a program coded in diSessa's Boxer computer language. The researchers presented two forms of the software in order to determine if the "cover story" affected students' responses and conceptions. One form presented a "dots and frame" cover story. The other cover story presented a moving object inside a box car. Elmira was purported to be a "microworld," in the spirit of other microworlds such as LOGO (see Papert, 1980). The researchers investigated what they considered the "world-ness" of the microworld for the students. By "world-ness" the investigators meant how much of a "closed problem space" the world represented and how interconnected the examples were considered to be by the students. They claimed that the software did not function as a world due to inconsistencies in how the students approached problems within the purported world.

In their investigation of how students solved the puzzles, the authors investigated students' interpretation of each problem and the strategy employed in solving each problem. They identified problem interpretations and problem solving strategies. Because there was not a one to one mapping of situation assessment to problem solving strategy, the authors concluded that the microworld did not have problem set closure and thus did not function as a "world."

Concerning the cover story presented in the computer simulation, those who used the boxcar cover story used the "relative motion" interpretation more often than those who used the "dot and frame" cover story. However, those students who used the dot and frame cover story, seemed to use the computer as a more general tool, seeing connections between puzzles that were not seen by those who used the boxcar cover story ; thus implying that the more abstract cover story associated with the software provided more transfer possibilities. The fact that those students who used the boxcar cover story used the relative motion interpretation may be due to the more familiar nature of a concrete representation of the puzzle. It appears that there is a tradeoff between ease of comprehension and ease of transfer, with the more representationally abstract story being more powerful by means of the number of transfer possibilities but correspondingly difficult to understand.

The authors considered the boxcar cover story to be a concrete situation to which students could relate. However, with decreasing use of rail travel, it is questionable that this is true. Another consideration is the influence of using the word "frame" for the dot and frame cover story. Since the ability to mentally "view" situations from different frames of reference is important for comprehension of relative motion problems, use of the term "frame" may allow for transfer of a mindset to other relative motion problems. In the boxcar case, the term boxcar is not used to represent a frame of reference; thus use of the boxcar "cover story" may provide fewer transfer possibilities. This possibility would be interesting for future research; it was not addressed in the Metz and Hammer study.

The authors concluded that in many ways, Elmira did not function as a world. Support for this position involved the assertion that students employed many different representations of motion--thus the microworld did not resemble a "world"; similarly, interpretation of a problem did not have a one-to-one correspondence with students' approach used.

There is cause to view the efficacy of the software with skepticism on other grounds besides whether or not the software effectively works as a microworld. The software may buttress the misconception that motion should be viewed from one "correct reference frame" The implied "correct reference frame" is the screen. In addition, the software may buttress the misconception that rest is fundamentally different than motion.

Hewson (1984) and Zietsman & Hewson (1986) explored a confusion that students have between position and velocity in studies that used a microcomputer simulation to ameliorate the misconception. Hewson (1984) used a sample of eighty-five university students in an introductory physics class. In his test, diagnostic questions searched for a misconception regarding position and velocity which equated equal position with equal velocity. (See McDermott (1982) for a description of this misconception.) He found twenty three students who demonstrated the misconception. Fourteen of the students who displayed this misconception used computer simulation software which presented an extreme case in which a car, moving relative to the computer screen, passed a car which was stationary on the computer screen. Ten of the fourteen students who used the microcomputer program as an intervention, reversed their opinion and obtained the correct answers.

In analysis of these and other findings, Hewson (1984) said that in order for conceptual change to occur, the new conception must fit in seamlessly to the existing conception or the new conception must replace the existing conception. For the latter condition to occur, the new conception must be a more powerful explanatory force than the previous conception. Hewson spoke about the following hierarchy of qualities that could be attributed to a conception:

- intelligible (I),
- plausible (P),
- fruitful (F).

To use a new conception it must be at least in the IP level, he asserted.

Ueno, Arimoto and Yoshika (1992) posited that the manner to remediate students' misconceptions in the relative motion arena is to recontextualize relative motion scenarios.

The framework of the paper "Learning Physics by Expanding the Metacontext of Phenomenon [sic]" by Ueno, Arimoto and Yoshioka (1992) involved commentary on the effect of experience in supplying preconceptions, the connection between everyday (non-technical) language and misconceptions, and the influence of interactive systems on students' preconceptions.

Concerning the effect of experience in supplying preconceptions Ueno, et al. (1992) stated:

> It seems to us that naive physics can more accurately be considered as an interactive system between cognitive agents, real objects and the physical environment rather than as systematic theories or knowledge in pieces in mind. (p.1)

Ueno, et al. (1992) asserted a connection between everyday (non-technical) language and misconceptions. The fact that the speed of an automobile is regularly cited without indicating the assumed frame of reference is but one example used by Ueno, et al. to buttress their point. They gave evidence that high school students involved in this research tended to believe that the only true motion of an object was that motion seen from a stationary platform relative to the earth. Motion viewed from other frames was seen as "appearance". This seems analogous to Saltiel and Malgrange's (1980) description of "proper velocity". Ueno, et al. explored the social context of misconceptions simultaneously with the language aspects and concluded: "there has not been enough research on the critical difference between the metacontext of everyday discourse and that of Newtonian." (Ueno, et al., 1992, p.2)

In my opinion, even a common textbook expression of Newton's First Law, (an object at rest remains at rest, an object in motion remains in motion), reinforces a misconception that an object may be considered to be at rest. Similarly, Swarz has indicated that Newton's first law basically defines reference frame (Swarz, 1989).

Ueno, et al. (1992) stated, "Learning is not only an event in mind but can also be usefully characterized as the exchange of an interactive system comprised of cognizers and particular situations." (p.2) In this context, the "natural" frame of reference and natural events are discussed. Ueno, et al. indicated that "'the static ground'" as a frame of reference is tacitly considered as natural" (p.3) and "motion such as falling down and rolling down on the slope are perceived as 'natural' in the same way that an object at rest on a horizontal, flat, rigid surface is regarded only as 'natural' or given." (p. 3)

Ueno, et al. (1992) indicated that physics learning is hampered by everyday discourse, cultural norms and the difficulties embedded in everyday context. In order to overcome such difficulties, Ueno, et al. indicate that "expansive recontextualization" (p.25) is necessary. While according to Ueno, et al.'s experimental data analysis, recontextualization does appear to produce right answers on multiple choice paper and pencil tests, it would be interesting to see whether such recontextualization is transferable to students' everyday experience. An interesting follow-up to Ueno, et al.'s research listed in this paper would be a study of the transfer of knowledge and spontaneous selection of appropriate context in solving non-academic physics problems. Without some sort of link to the real world, many and possibly most physics exercises are viewed by students as academic and removed from the "real world" of the students' everyday experience.

Conclusions

A variety of alternative conceptions have been documented in the study of relative motion. Documented alternative conceptions include:

- equal position implies equal velocity (see McDermott, 1982; Hewson, 1984; Zietsman & Hewson, 1986).
- acceleration equals velocity (see Halloun & Hestenes, 1983).
- "fighting velocities" (Aguirre and Erikson, 1984).
- true velocity versus "apparent" velocity (Saltiel and Malgrange, 1980, Ueno, et al., 1992).

It seems that one organizing influence is students' concern over the source of non-accelerated motion (see Clement, 1982; Halloun & Hestenes, 1985; Saltiel & Malgrange, 1980). Another way to organize some of the findings is to look at students' everyday experiences and how non-technical language and lack of experience with frames of reference hinders acquisition of a scientific view of relative motion (see, for instance, Ueno, et al., 1992). Students' view of motion as "true" or illusory is particularly problematic, as it betrays a prejudice toward viewing the "static earth" as the only true reference frame (see Camp, et al., 1994; Ueno, 1992; Saltiel & Malgrange, 1980). It does seem clear that students frequently do not spontaneously or consciously consider alternative frames of reference besides the default frame of reference (which is generally the earth). Confusion between the technical terms and meanings of the terms position, displacement, and velocity compound the difficulties students have in this area. (See, for instance, Ueno, et al., 1992)

It seems clear that many (if not most) students do not initially view motion as defined relative to a reference frame. The idea that stillness and motion are not fundamentally different is particularly counter-intuitive (see, for instance, Camp, et al., 1994; Kuhn, 1970; Saltiel & Malgrange, 1980; Sequeira & Leite, 1991; Swarz, 1989). Besides the magnitude of the velocity, the concept that direction of travel is dependent on reference frame is problematic for students (see, for example, Inhelder & Piaget, 1958; Saltiel & Malgrange, 1980).

Concerning treatments, the results of Metz & Hammer's (1993) research raise the question of whether to use abstract representations or concrete representations; the tradeoff being generality versus intelligibility. Ueno, et al.'s (1992) recontextualization strategy, which would presumably allow students to mentally operate with frames of reference besides the earth frame, seems promising; I am concerned about whether students could visualize relative motion scenarios in a foreign frame of reference (such as space), as it would be outside their realm of experience. (Space videos, such as those referenced in Camp, et al., 1994, may bridge the experience gap.) The use of a computer simulation by Hewson (1984) was apparently a very effective, though a costly way to display an extreme case. It seems that in this case similar efficacy could be achieved with manipulatives.

Vacillation of reference frame appears problematic. Preliminary results, from clinical interviews I conducted, suggested that during solution of a problem some students may unknowingly change their default frame of reference. It seems that this inconsistency of default reference frame is a possible alternative explanation of some difficulties displayed by subjects in McCloskey, et al.'s (1983) study.

In addition, results of the aforementioned studies as well as results from clinical interviews I conducted, suggested that students need to: 1. Realize that different frames of reference exist; 2. Understand that the magnitude of the velocity vector is dependent on reference frame (and the magnitude may be 0 for an object that is "moving" relative to the ground). 3. Understand that the direction of the velocity vector is dependent on the reference frame. 4. Select the reference frame that is most expedient. (This position has frequently been voiced by Amherst, Massachusetts High School Physics teacher Charlie Camp.) 5. Be able to visualize scenarios viewed from different reference frames.

Lastly, it appears clear that study of relative motion opens up numerous quagmires for students. Serious students must grapple with the apparently paradoxical equivalence of motion and non-motion and realize that neither is a property of an object, or necessarily the result of a force applied on (or "contained within") an object, but rather, motion and non-motion are defined relative to the reference frame. Perceptual difficulties may hamper the student's progress. Non-technical use of technical terms and other complications of "non-scientific" interactions with relative motion further complicate the task of student understanding. Oversimplification (such as equating position and velocity) and anthropomorphism (displayed in the conception that velocities "fight" each other) may also hinder a student's progress. The existence of these and other difficulties, including visualization difficulties, indicate that the task of learning relative motion is indeed complex and that additional research is necessary to classify students' relative motion conceptions and to develop pedagogy to assist students in acquiring more expert understanding of Galilean relative motion.

Literature Review: Research On Educational Uses of Computer Simulation

Research conducted by Choi & Gennaro (1987) indicated that a computer simulation proved as effective as physical laboratory experience for teaching junior high students the concept of volume displacement. In a control-experimental treatment research design, it was shown that learning occurred via traditional laboratory experience or through a computer simulation. The time required for the computer simulation was twenty-five minutes, versus ninety-five for the lab.

Rieber (1991) showed gains by 4th graders in incidental as well as intentional learning following use of computer simulations which dealt with Newton's laws of motion. In an experiment in which one treatment group saw static graphics and another group saw animated graphics, Rieber concluded that the animation group performed better on measures of incidental as well as intentional learning, but also displayed more new misconceptions.

Barbara White (1993) cited numerous advances in 6th grade student performance on measures of understanding of Newton's laws of motion following use of inquiry activities and ThinkerTools simulations. Indeed, the 6th graders did better than high school students who were taught through other means. In designing the curriculum, White intended to:

> 1. Employ manipulable, linked representations for key abstractions.... 2. Make the phenomena easy to see and interpret.... 3. Create scaffolded inquiry activities.... 4. Reify the knowledge to be acquired.... 5. Foster collaborative learning.... 6. Facilitate model evolution by providing model progressions.... 7. Incorporate learning about scientific inquiry. (pp. 49-50)

Hewson (1984) and Zietsman & Hewson (1986) showed gains in student understanding of relative motion following use of a computer simulation which followed an extreme case model for remediating an alternative conception.

Andrea diSessa (see Adams & diSessa, 1991; diSessa, 1986; Sherin, diSessa, & Hammer, 1993), the author of BOXER, and

Seymour Papert (1980, 1993) advocate active programming within microworlds as a pedagogically effective use of computers.

Wiser (1992), along with a discussion of treatment gains, discussed alternative conceptions that were reinforced by interaction with a thermodynamics simulation. In similar fashion, Rieber (1991), in citing work by Barbara White and work he conducted, asserted that novices often do not attend to salient features of a simulation: "Even if students attend to an animated display, they often fail to notice the information it contains. For example, differences in motion or trajectory that an expert may see as obvious may be totally overlooked by a novice." (pp. 318-319) De Jong (1991), in a theoretical paper, also indicated that novices have difficulty with unstructured simulations; for novices, it is necessary to provide a structure. This view is in opposition to a free exploration approach to using a computer simulation.

Metz & Hammer (1993) showed treatment gains by high school students who followed a predict-observe-explain sequence with the BOXER computer microworld. They also examined the applicability of the term "world" to describe a computer microworld and concluded by questioning the suitability of the "world" metaphor for describing students' interaction with a computer microworld.

Williamson & Abraham (1995) showed gains in conceptual understanding of the particulate nature of matter by university chemistry students who viewed computer animations both in a lecture environment and in a combined lecture/interactive lab environment. While there was not a significant difference in scores of conceptual understanding of the particulate nature of matter between animation groups, there was a significant difference between scores of students who were exposed to animations and scores of the control group on the measure of conceptual understanding (called PNMET by the authors). There was no significant difference in course achievement according to the authors. They reasoned that "analysis of the questions on the course examination revealed that a majority of the questions on the instructor-constructed test were algorithmic in nature." (p. 530) They cited Gabel & Bunce, 1991; Nurrenbern & Pickering, 1987; Pickering, 1990; and Sawrey, 1990, as supporting the position that conceptual understanding of the particulate nature of matter is not required to solve algorithmic or symbolic problems.

Mayer & Sims (1994) indicated that presenting animation with an explanation assisted students with high spatial ability; it did not assist students of low spatial ability.

Monaghan & Clement (1994a, 1994b) showed that visualization can be fostered by interaction with a computer simulation. This visualization occurred both during and after interaction with the computer simulation. They also provided evidence that the structure of the activity performed with the computer simulation (Monaghan & Clement, 1994b) affected the approach that students used to solve problems.

The dissertation study conducted was designed to build upon results displayed in previous studies. Additionally, in this study I sought to extend understanding concerning effective physics (particularly Galilean relativity) pedagogy, to test performance following educational computer simulation use, and to identify types of problem solving approaches used by students who interacted with computer simulations within different activity structures as well as to identify types of activities that may foster specific problem solving approaches. Specifically, this study sought to identify conditions that may foster students' use of qualitative problem solving methods (such as visualization) as well as conditions that may foster students' use of quantitative problem solving methods (such as algorithm use).

CHAPTER II

RESEARCH DESIGN

Introduction

In stating research questions, the terms "decontextualized numeric simulation activity" and "contextualized visual simulation activity" were used. The first part of the term refers to the "cover story" (see Metz & Hammer, 1993), either contextualized (e.g., objects are given names such as dog, bike and house) or decontextualized (e.g., objects are given nondescript names such as black circle, gray circle, and white triangle). The second part of the term refers to the primary form of feedback provided to the student following the student's predictions, either numeric (in the form of numeric speeds of objects) or visual (in the form of an animation). More details are contained in the description of the treatment.

Research Questions

1. Using a measure of relative motion understanding, what is the difference between the performance of students who engage in decontextualized numeric simulation activities and the performance of students who engage in contextualized visual simulation activities?
2. What differences can be identified between subjects' relative motion understanding before, during and after interacting with computer simulation activities?

Experimental Procedure

There were two major components of this study: an individual interview paired exercise component and a classroom small group component. In both components, the treatment will follow a pretest-treatment-posttest design.

Pretest/posttest

For both the classroom and individual studies, the pretest and the posttest were identical and taken individually by each student. For both the interviewed and classroom students, the test required less than 40 minutes, with the posttest generally requiring less time than the pretest. The multiple choice pretest/posttest questions were designed to test both qualitative and quantitative understanding of Galilean relativity concepts. The questions had been slightly modified following pilot testing in previous studies (see Monaghan & Clement, 1994a, 1994b). The pretest/posttest questions are listed in the appendix. (The use of confidence scales associated with each question closely resembled the use of confidence scales in Brown, 1987/1988.) For the classroom studies, the posttest was conducted on the last day of the hour long treatment. Because the treatment lasted approximately 1 hour, it was conducted over two consecutive class meeting periods. At the end of the second treatment period, the posttest and the questionnaire were administered. For the interview studies, following the treatment, the posttest was scheduled at the next available open period convenient for the students and the interviewer (never more than 4 days following the treatment).

Subjects

There were two sets of subjects. In the individual treatment conditions, student volunteers selected from a regional high school worked in groups of two. Four groups of two were involved in each of the two individual treatment conditions, for a total of 16 students. In the classroom treatment conditions, four intact classrooms were involved. The classes were composed of two honors classes and two standard level classes from a private high school.

For the individual treatment conditions, pairs of high school student volunteers will partake in the study. Any student (under 18 years old) who wished to participate in the study needed to have a parent or guardian formally grant permission. All students were informed of the nature of the study and all participants were notified that they could cease participation in the study at any time.

For the classroom study, students were also informed of the nature of the study and were informed that they may cease participation in the study at any time.

Interview Treatments

In the interview studies, there were two treatment conditions: condition CV, the contextualized visual treatment, and condition DN, the decontextualized numeric treatment. In each case, the treatment consisted of interaction with 4 computer simulations. I had previously constructed the simulations with RelLab (Horwitz, Feurzeig, Shetline, Barowy, & Taylor, 1991, 1992) software which had been modified using ResEdit (Apple Computer, Inc., 1984-1990), on an Apple Macintosh Powerbook 160 computer. During each treatment, each pair of subjects made predictions, observed computer output, and explained any discrepancies between their predictions and the observed computer output. For each condition, this interaction took approximately one hour. During the treatment, each student was encouraged to discuss answers and reasoning with his or her partner. Both the computer output (seen by the students) and the students' protocols were videotaped. The individual treatments were conducted at the participants' school in a laboratory setting; videotaped think-aloud protocol as well as written data were collected. Table 2.1 contrasts characteristics of the two treatment conditions.

Table 2.1

Characteristics of Treatment Conditions

CONDITION	context provided	animation seen	numeric velocity data seen	direction prediction	speed prediction
CV	Yes	Yes	No	Yes	No
DN	No	No	Yes	No	Yes

Classroom Treatments

As in the individual studies, there were two different treatments in the classroom studies. The structure of classroom treatments CV and DN were very similar to individual treatments CV and DN. As in the individual treatments, each classroom treatment consisted of activities with 4 computer simulations, during which students, working in pairs, made predictions, observed computer output, and discussed with their partners discrepancies between their predictions and the observed computer output. Classroom treatments CV and DN took approximately one hour, split into two classroom sessions. The investigator presented the computer simulations to all members of the class simultaneously. Data collected during the classroom treatments consisted of written pretest answers, written worksheet responses, posttest answers, and questionnaire responses.

Data Analysis Methods

For the classroom study, statistical tests of significance were performed measuring differences between students' performance on the posttest and their performance on the pretest.

For the individual study, statistical tests of significance supplemented qualitative analysis of student "think aloud" protocol. Protocol data in the form of videotape, audiotape, and written responses as well as transcriptions of interviews were selectively analyzed. Protocol analysis utilized a "constant comparison" methodology (see Glaser & Strauss, 1967).

Sample Exercises: Galilean Relativity 1 Computer Simulation

Below, the activities performed by students with one of the four computer simulations are described. These procedures are applicable to both the classroom study and the individual study.

In treatment condition CV, the contextualized visual treatment condition, pairs of students were given a "real world" cover story in which the objects (e.g., the triangles and the circles in the following simulation) were given names such as dog, tree, bike and house. In condition DN, the decontextualized numeric treatment condition, the objects were given nondescript names (black triangle, white triangle, gray circle, black circle). In both conditions, the objects displayed on the screen were iconic in nature (see White, 1993); this iconic nature of the objects was intended to facilitate transfer. As shown in a study by Metz & Hammer (1993), a decontextualized condition (such as condition DN) may more easily facilitate transfer. However, it was also expected (as indicated in Metz & Hammer, 1993) that some students may be unable to apply their experience with a decontextualized condition to real world (contextualized) instances, such as those depicted in the relative motion test (see appendix).

Initially, in treatment CV, the simulation was run from the default frame of reference for at least 10 seconds. (In this case, the white triangle 1 defined the default frame of reference.) As an example, the following two screen "snapshots" show the first simulation at time 0 and time 4.8 seconds (see figures 2.1 and 2.2). This was followed by a timer reset. The simulation was then run again. Following reset of the timer, the simulation was then run a third time.

In condition DN, the students were shown the speed of each object. The students did not see animations. See figure 2.3 for sample data provided to the DN students.

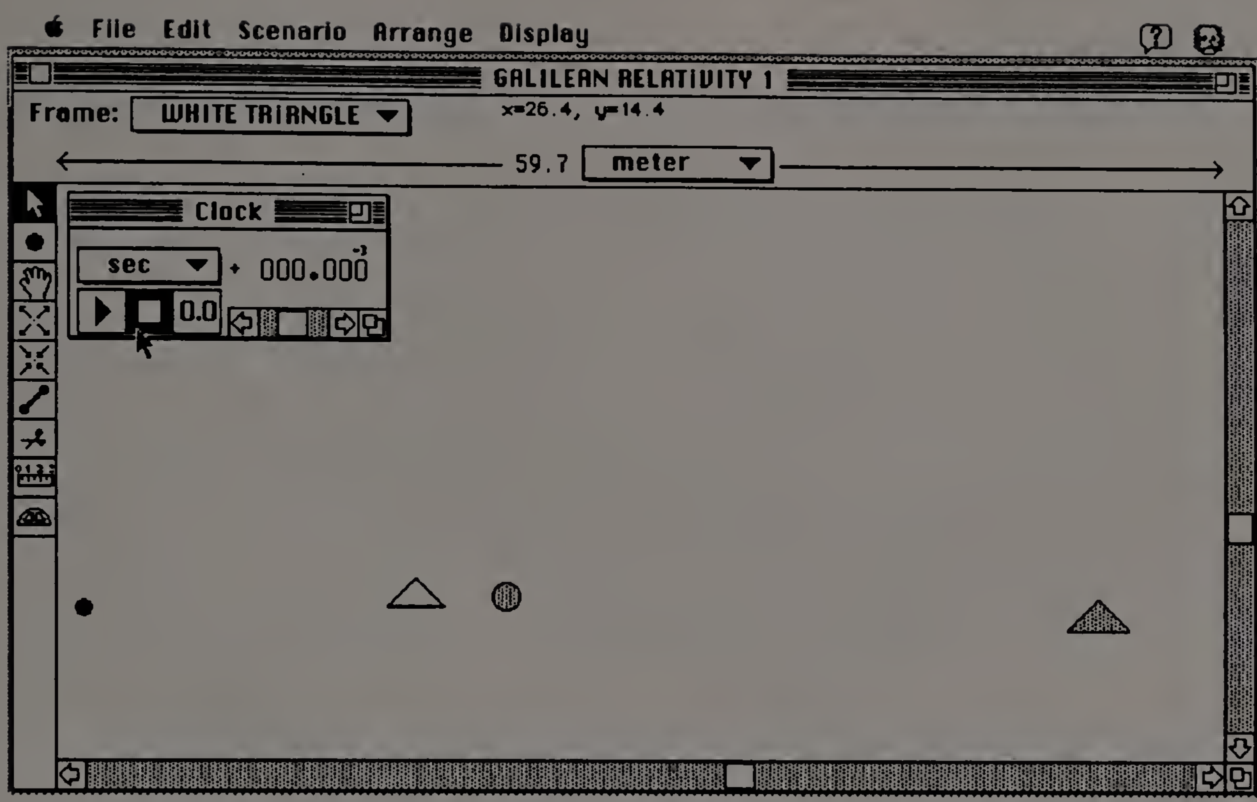


Figure 2.1

Initial state of first simulation (both conditions)

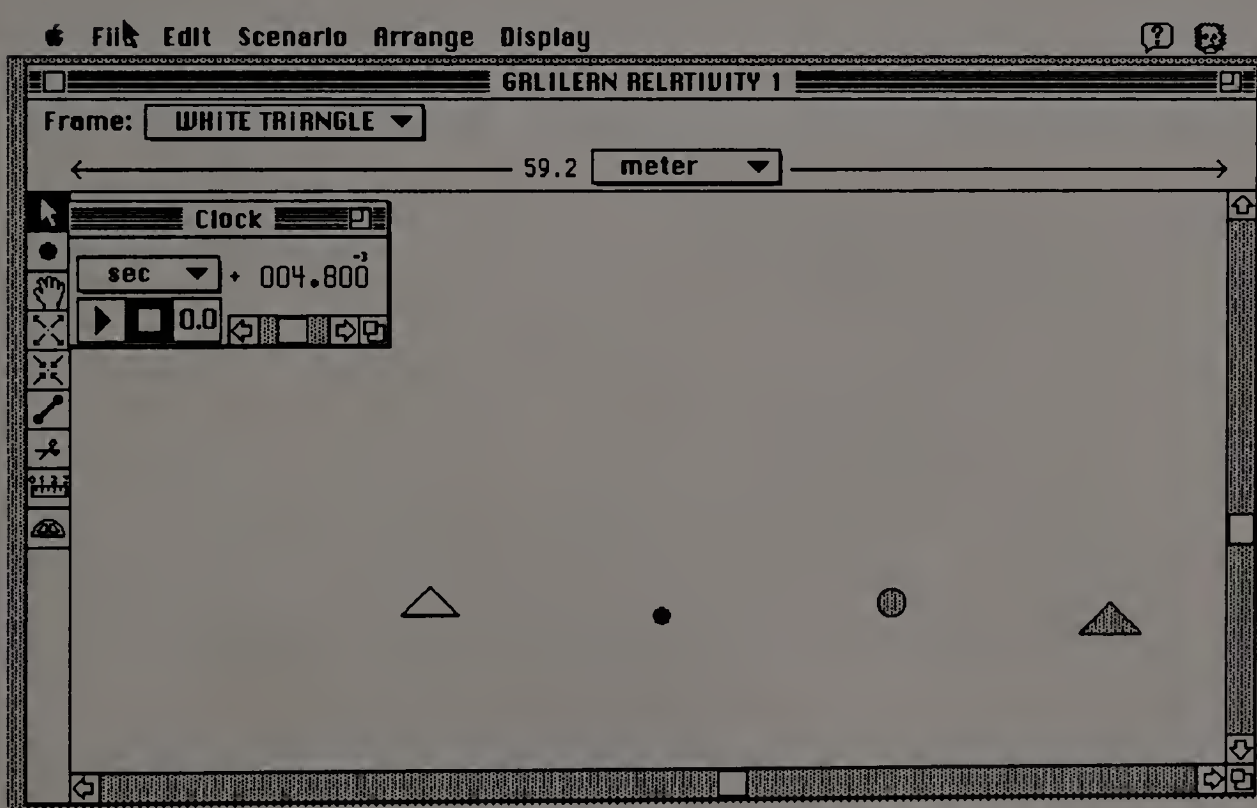


Figure 2.2

First computer simulation animation after 4.8 seconds (CV condition only)

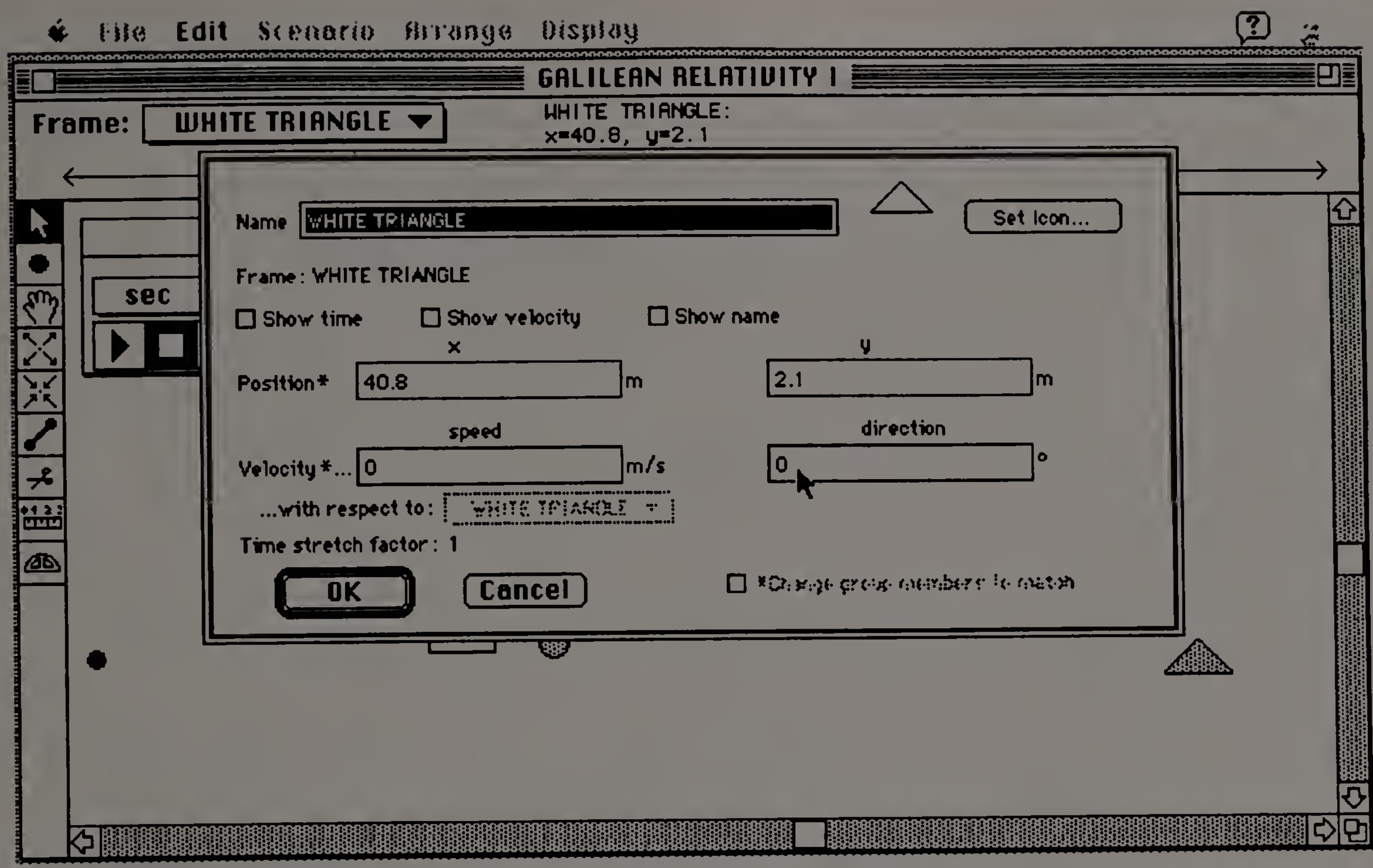


Figure 2.3

First computer simulation sample velocity data

(DN condition only)

Next, for both conditions, the frame of reference was changed. (See figure 2.4.) Each pair of students made a prediction for the expected output of the computer simulation. In the contextualized visual (CV) treatment condition, predictions concerning the direction of travel of objects were made by each student pair. In the decontextualized numeric (DN) treatment condition, predictions concerning the speed of objects relative to the new frame of reference were made. In condition CV, only visual feedback was given. In condition DN, the students received numeric feedback on the speed of the objects for which they had made predictions.

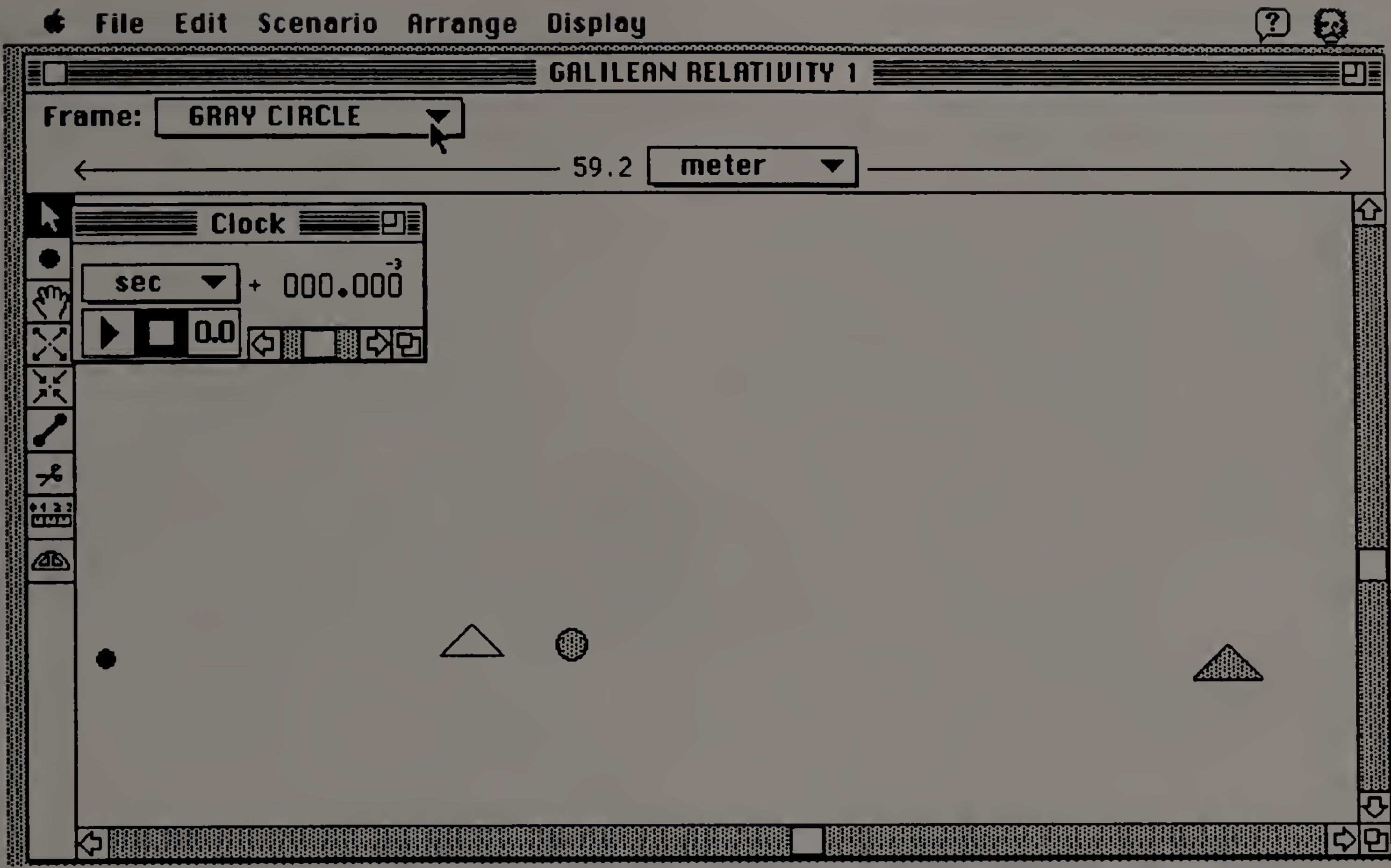


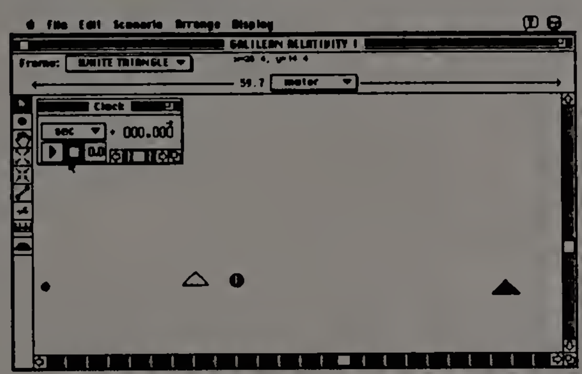
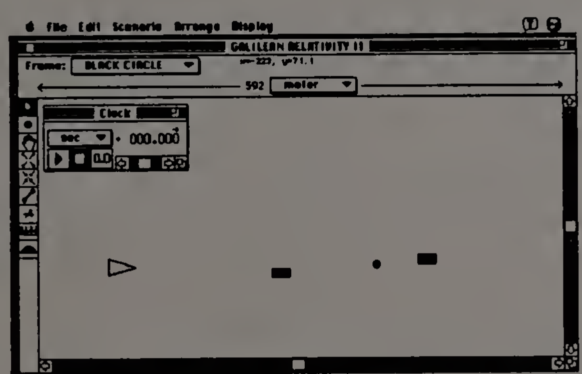
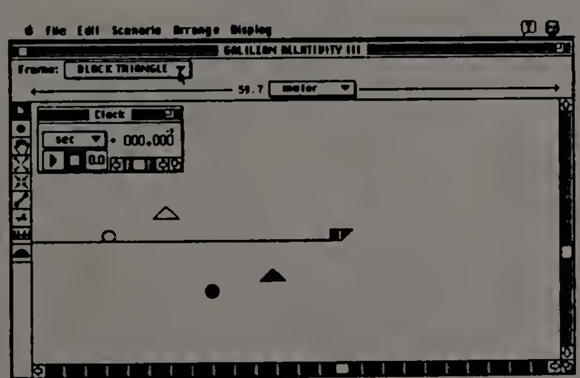
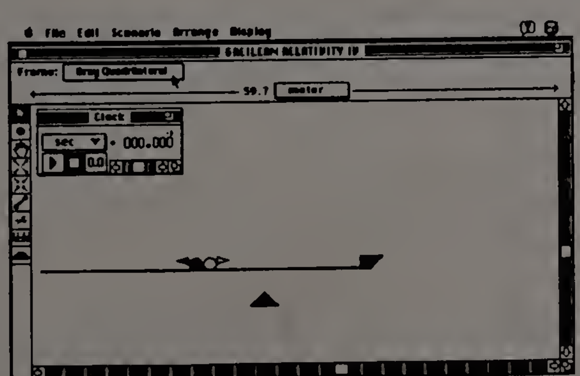
Figure 2.4

First simulation after frame change (both conditions)

Table 2.2 lists a sample screen snapshot from each of the computer simulations used by students in both the individual and classroom treatments and lists the nature of the prediction and the nature of the feedback provided for each treatment condition. Figures 2.5 through 2.8 reveal the initial conditions of each of the simulations. Velocity vectors, representing the velocities of the objects relative to the initial frame of reference, are shown above each object. (Note: These vectors were not seen by students. CV treatment students viewed animations only (e.g., see figures 2.1 and 2.2). DN treatment students saw numeric velocity information only (e.g., see figure 2.3).)

Table 2.2

Simulation Activities Used by Students

simulation	sample screen	Condition CV predictions/ feedback	Condition DN predictions/ feedback
1		directions/ visual	speeds/ numeric
2		directions/ visual	speeds/ numeric
3		directions/ visual	speeds/ numeric
4		directions/ visual	speeds/ numeric

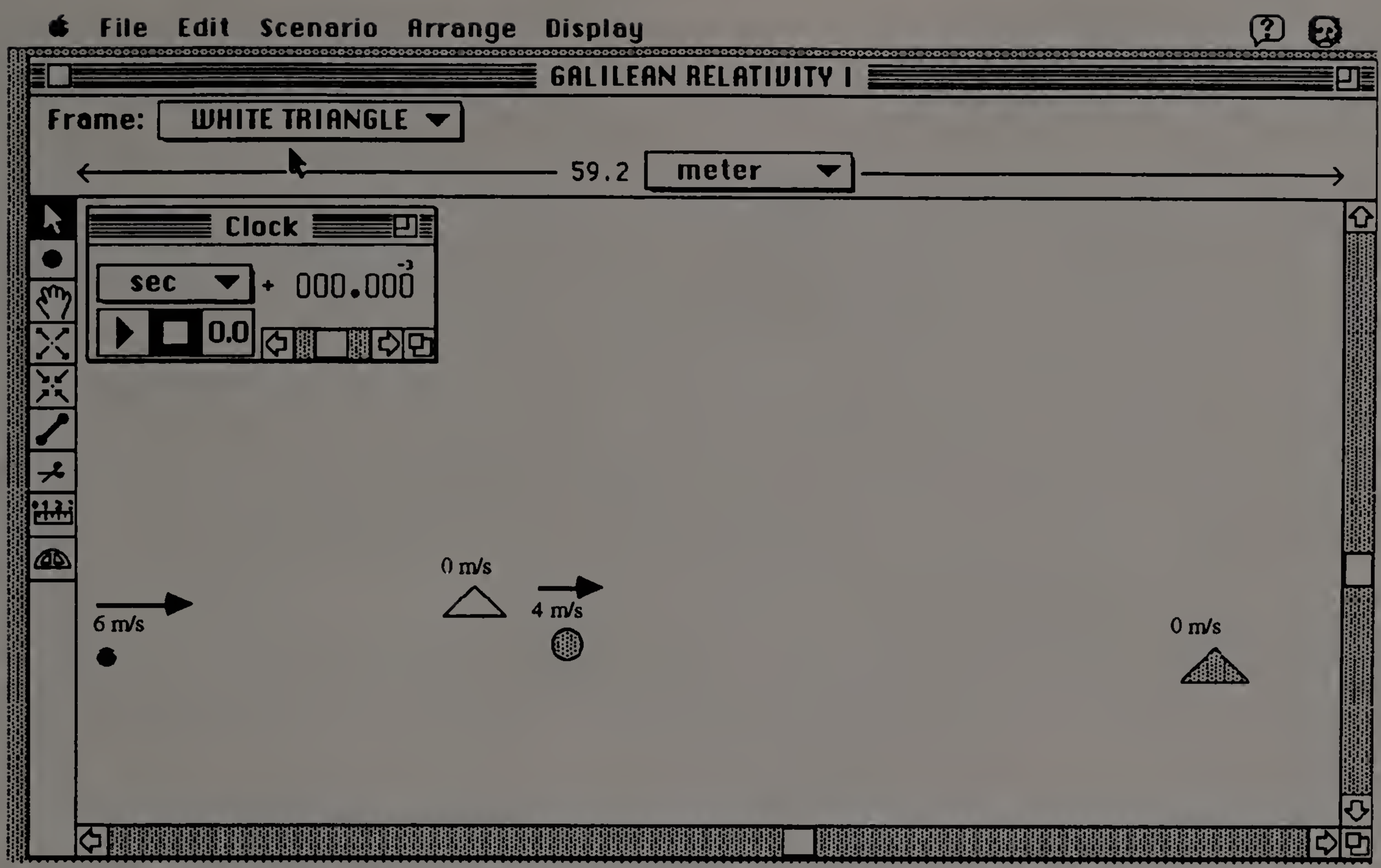


Figure 2.5

Simulation 1 initial conditions

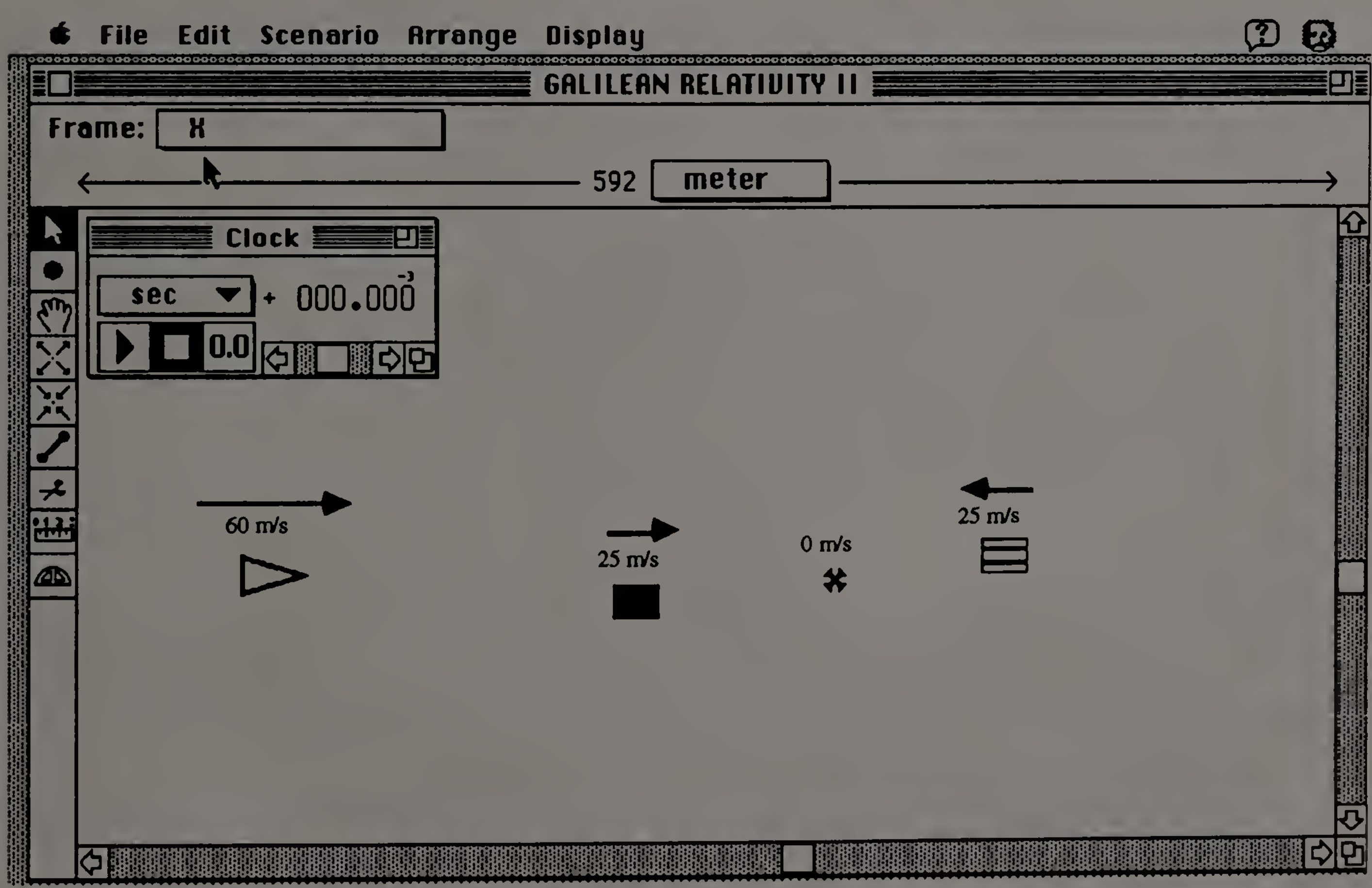


Figure 2.6

Simulation 2 initial conditions

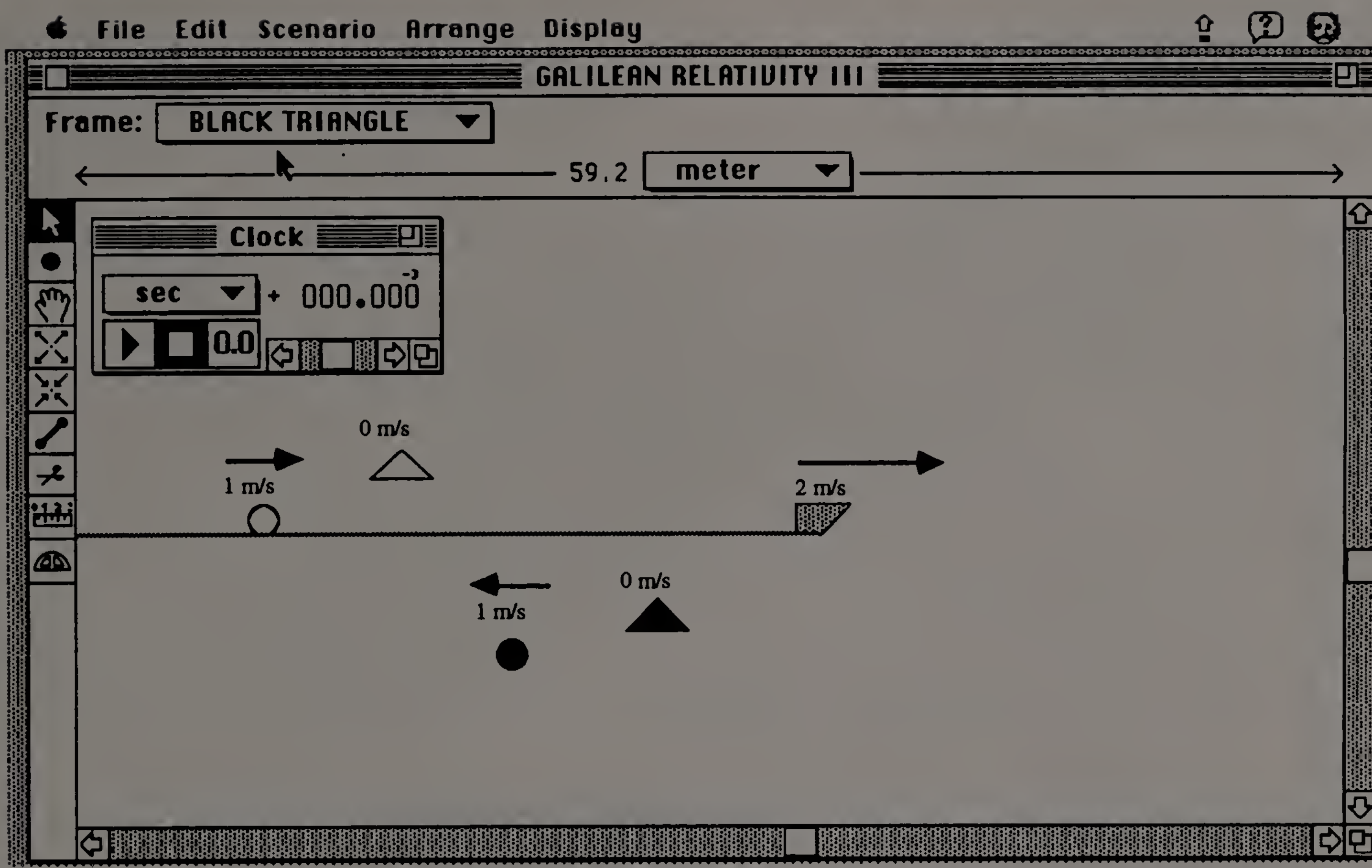


Figure 2.7

Simulation 3 initial conditions

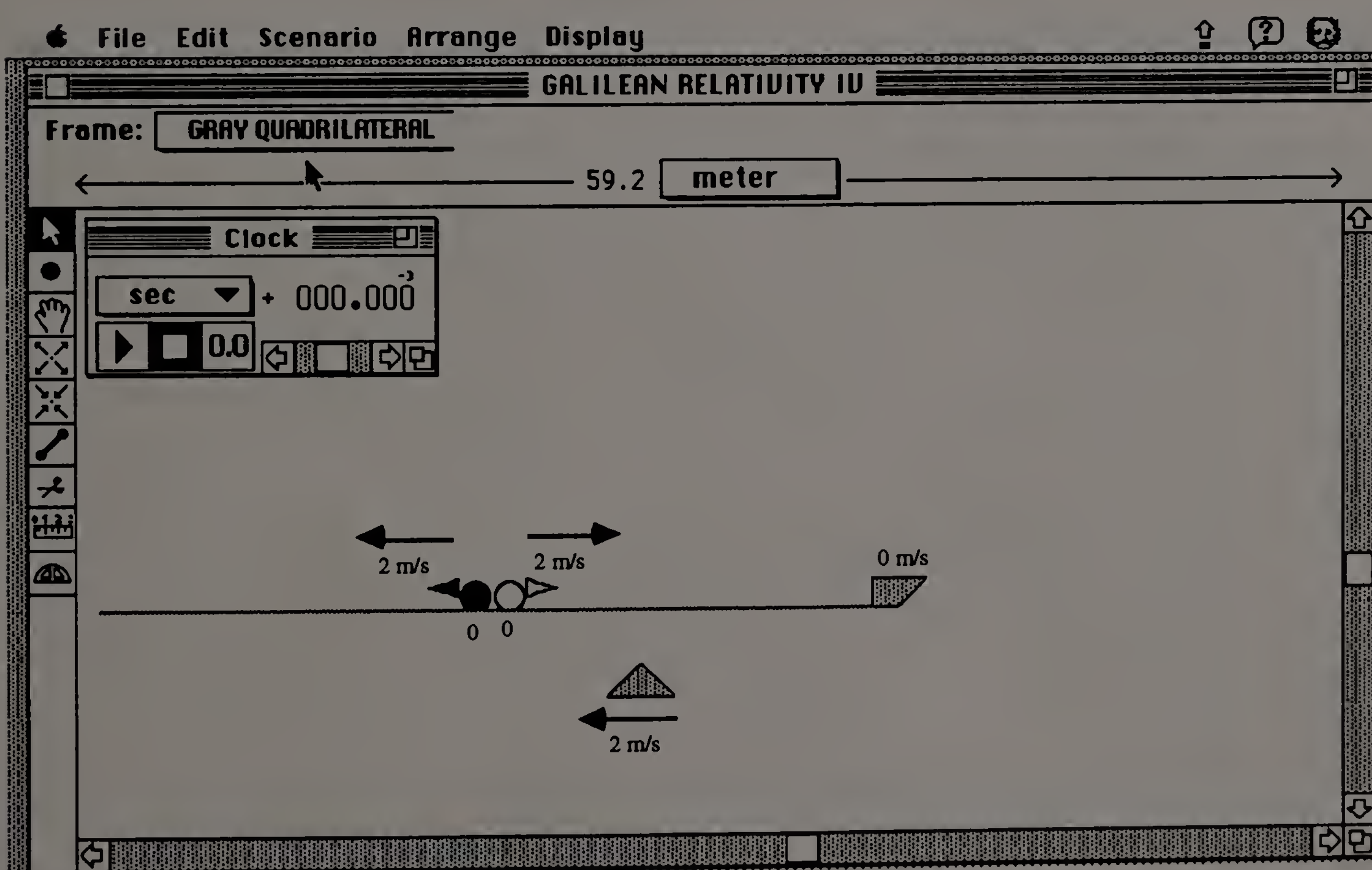


Figure 2.8

Simulation 4 initial conditions

As stated above, in condition CV, for each of the four simulations, students made predictions concerning the direction of travel of objects on the computer screen. Interactions with the simulations in this manner were designed to create cognitive conflict due to anticipated incorrect predictions about the motion of objects whose direction on the computer screen changes when the frame of reference changes. (See, for example, Monaghan & Clement, 1994a, 1994b.) It was expected that students who made qualitative predictions would attend to the anomalous case and alter their models of relative motion as a result. This was expected to be facilitated by the reflective nature of the predict-observe-explain task (for examples of the use of predict-observe-explain tasks, see Linn & Songer, 1991; Metz & Hammer, 1993).

In condition DN, for each of the four simulations, students predicted the speed of objects on the screen. It was anticipated that often these students would create algorithms that would enable them to solve relative motion problems.

CHAPTER III

CLASSROOM AND INTERVIEW STATISTICAL RESULTS

Introduction

In this chapter, classroom students' performance on the pretest and their performance on the posttest is compared. Each class' posttest performance is compared to each class' pretest performance and the mean gain on the measure is compared between groups. Additionally, I list the frequency of incorrect predictions (for each of the predict-observe-explain tasks) for each class.

Following statistical analysis of the classroom data, analysis is done on the interviewed groups. Analysis of the interview groups involves within group posttest versus pretest comparisons, a between groups gain comparison, and frequency of correct predictions data.

This chapter addresses whether any statistically significant learning, as measured by performance on the relative motion diagnostic test, occurred following each of the two conditions. It also addresses whether there were statistically significant performance differences between groups--providing information on the relative impacts of the two treatments.

In this chapter, I hypothesize conditions under which students may experience conceptual change as a result of interaction with the computer simulation activities. The hypotheses are based on theory concerning the role of conceptual conflict. I suggest that a likely source of conceptual conflict can be incorrect predictions during the predict phase of predict-observe-explain tasks performed within the context of the computer simulation activities. Data concerning incorrect predictions made by students in both conditions is presented.

Hypotheses

Students in the contextualized visual condition were expected to perform better on the measure than students in the decontextualized numeric condition. This expectation was based on the belief that visualization of transfer problems would be assisted by interaction with the animations of the contextualized visual condition. Additionally, providing the students with a context was expected to assist students in their understanding of the base, i.e., the computer simulations. However, this thesis was unclear, for, as suggested by Metz & Hammer (1993), a decontextualized condition may allow for more transfer by students--provided that the students could understand the base (computer simulations). It was expected that some students in the decontextualized numeric condition may develop algorithms to assist their solution of problems, and that these algorithms may be poorly understood. If this were the case, decontextualized numeric students' confidences in their answers may be lower than contexutalized visual students confidences.

Classroom groups' relative motion test results

In the first study, students' performance on a measure of relative motion learning was studied. In this study, an entire standard level physics class taken from a large private school was given the CV treatment (see description above) and is called the CVstd group. Another entire standard level physics class from the same school and the same teacher did not receive a treatment and is called the CONTROLstd group.

A posttest-pretest comparison was performed on the 19 member CVstd group. (Only students who took both the pretest and the posttest were included in the sample.) The pretest mean was 36%. The posttest mean was 47%. A one-tailed t-test yielded a statistically significant result with $p<.01$. The 22 member control group's pretest mean was 45%. Its posttest mean was 49%. The control group's posttest-pretest difference was not statistically significant. When the posttest-pretest difference was compared between the CVstd group and the control group, a one-tailed t-test yielded a marginally significant result with $p<.10$.

In the second study, two entire honors physics classes in the same school were compared. One class received the contextualized visual treatment (CVhon group); the other received the decontextualized numeric treatment (DNhon group). A posttest-pretest comparison was performed on each group, using one tailed t-tests. Both the CVhon group and the DNhon group showed statistically significant gains on the measure, with $p<.01$ for the DNhon group and $p<.05$ for the CVhon group. The 16 member DNhon group's pretest mean was 58%; its posttest mean was 72%. The 19 member CVhon group's pretest mean was 58%; its posttest mean was 68%. A comparison of the CVhon group and the DNhon group showed no statistically significant difference between groups in posttest-pretest difference.

Table 3.1

Classroom One Tailed T-test Results:

Posttest/pretest and Gain Comparisons

group	n	pretest mean	posttest mean	p	mean gain	p
CVstd	19	36%	47%	<.01	11%	<.10
control std	22	45%	49%	N.S.	4%	
CVhon	19	58%	68%	<.05	10%	N.S.
DNhon	16	58%	72%	<.01	14%	

Gain Comparison Between Classroom Groups

I expected the CVhon group to perform better on the measure than the DNhon group, hypothesizing that the animation combined with a recognizable context would make the simulation easier to apply to problems. I expected the CV condition to foster visualization and expected visualization to assist problem solution. However, five of nine test questions requested a numeric answer; some students may be able to calculate answers to these questions without visualization. Also, it is possible that some students were able to take numeric information provided by the DN condition and convert it to a visual representation. This skill could then be applied during problem solution. This may be particularly true for honors students who may be fluent in their use of numeric representations. Also, based on examination of students' predictions, the CV predictions were easier than the DN predictions.

The CV condition may have been sufficiently easy for students that little dissonance and little learning occurred.

There was not a statistically significant difference between the CVhon and DNhon groups' gains on either the entire diagnostic test or on individual questions.

Classroom Groups' Prediction Accuracy

Theoretical Framework

As shown in figure 3.1, I hypothesize that there may be an optimal confusion level that may enable students to get the most out of a learning experience. This "optimal confusion" level occurs when the student is capable of processing anomalies which effected cognitive dissonance, yet the dissonance is great enough to facilitate "deep" processing characteristic of conceptual change. This optimal confusion level is similar to Vygotsky's (1978) theory of the zone of proximal development; however, instead of an authority or helper that necessarily facilitates conceptual development, interaction with the activity itself can lead to conceptual development.

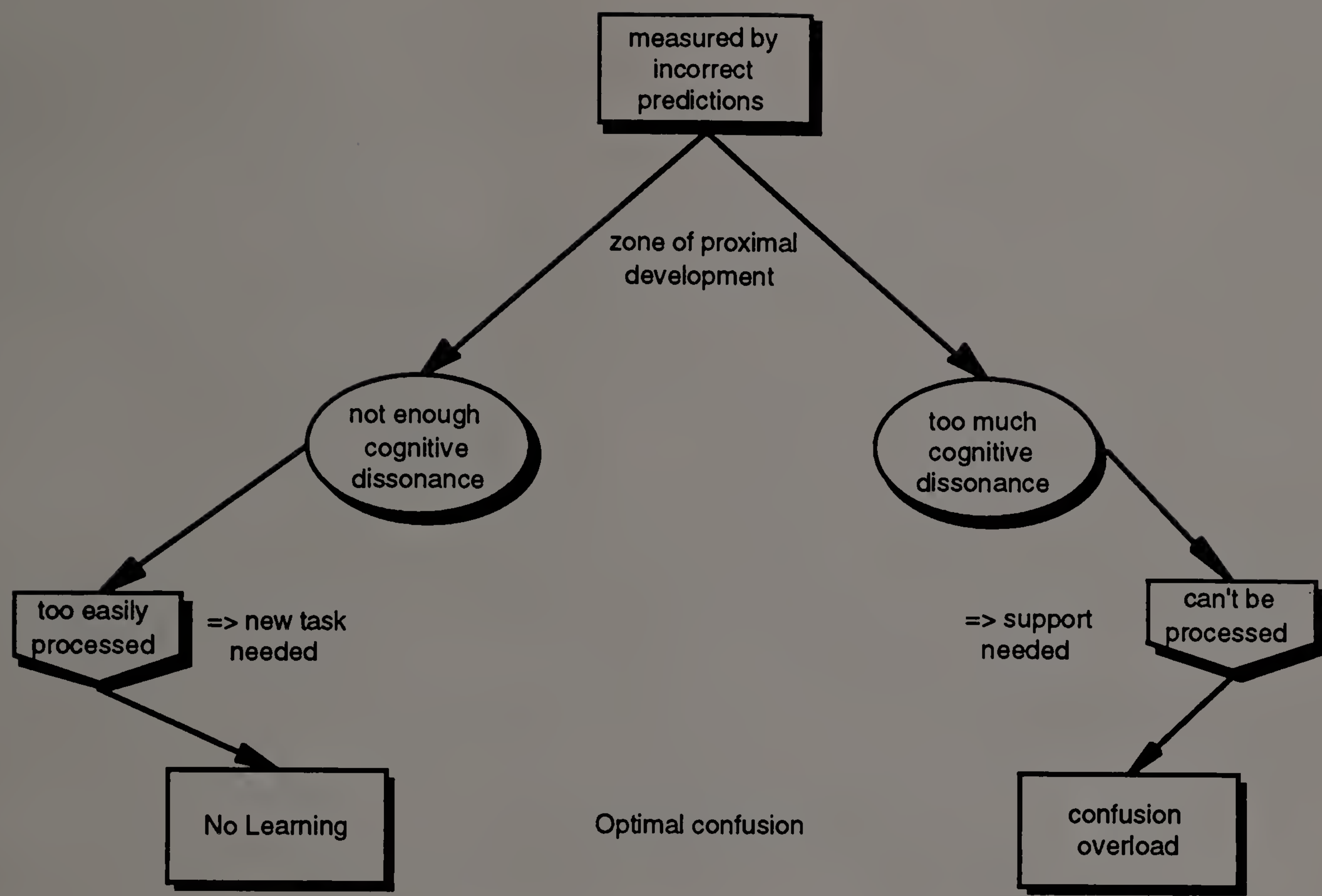


Figure 3.1

Cognitive dissonance framework

Classroom Prediction Accuracy

As can be seen by the following data, the DN condition appears to present more difficulties for students than the CV condition. This appears particularly true for simulations 3 and 4. The fact that more difficulties appear to be present in the DN condition may explain gains that the DN students made on the measure; students may experience conceptual change due to dissonance effected by incorrect predictions. Tables 3.2, 3.3, 3.4, and 3.5 list the prediction accuracy for the CV and DN classes; all students who recorded responses for an item are included in the percentage correct data.

Table 3.2

Classroom Simulation 1 Prediction Accuracy

Class	white triangle	grey triangle	black circle	grey circle
CVhon	83%	83%	67%	83%
DNhon	88%	71%	65%	88%

Table 3.3

Classroom Simulation 2 Prediction Accuracy

Class	X	white triangle	black rectangle	striped rectangle
CVhon	89%	100%	67%	100%
DNhon	89%	100%	83%	61%

Table 3.4

Classroom Simulation 3 Prediction Accuracy

Class	black triangle	black circle	white circle	grey quadrilateral
CVhon	100%	100%	94%	100%
DNhon	63%	56%	75%	100%

Table 3.5

Classroom Simulation 4 Prediction Accuracy

Class	black circle	black triangle	white circle	white triangle	grey triangle	grey quad.
CVhon	90%	70%	90%	95%	95%	100%
DNhon	69%	56%	75%	69%	81%	61%

Based on the results of students in the interview studies, I expected the DN classroom students to have more difficulty with the predictions than the CV classroom students. Indeed, when the number of correct predictions was compared between groups, a one-tailed t-test yielded a significant result with $p<.05$. As shown in table 3.7, the 14 DN students averaged 14 out of 18 correct; the 18 CV students averaged 16 out of 18 correct. (Only those students who responded to all prediction requests were included.)

Table 3.6

Classroom Prediction Accuracy

Class	N	Mean	SD	p
CVhon	18	16	1.5	< .05
DNhon	14	14	4.0	

The fact that students in the DN condition had greater difficulty, based on the number of incorrect predictions, than students in the CV condition provides evidence that different processes may be required for accurate prediction of speed versus direction. Based on interview protocol, it appears that, indeed, different processes are involved in the DN predictions than in the CV predictions. For instance, based on protocol data (see chapter IV) it was expected that the prediction concerning the striped rectangle would be more difficult for DN classroom students than for CV classroom students. One-hundred percent of the CV students made an accurate prediction on this item; sixty-four percent of the DN students made an accurate prediction on the item. A Fisher exact test was done on this item to determine if the frequency distribution was different for the two group's predictions. Figure 3.7 details the results of statistical analysis of this prediction item.

Table 3.7

Simulation 2 Striped Rectangle Prediction Accuracy

Class	N	Correct	Incorrect	p
CVhon	18	18	0	< .05
DNhon	14	9	5	

In analyzing this result, one key element is that the DN prediction in this case may tend to be based on algorithmic reasoning, in which students refer back to previous problems and make statements like "so you add" (see chapter IV).

Interviewed groups' relative motion test results

CV interviewed students

On the whole, there were not statistically significant gains posted by the 8 students who comprised the CV interview group.

Within this small sample, it appears that three of the students displayed a ceiling effect, limiting the statistical inference that could be derived from the sample. Table 3.8 summarizes the results of the CV interviewed students on each of the relative motion questions.

Table 3.8

CV Interviewed Students' Test Performance

Question	1	3	5	7	9	11	13	15	17	Average
Pretest	50%	63%	88%	63%	88%	75%	88%	63%	38%	68%
Posttest	75%	75%	88%	75%	88%	88%	88%	88%	50%	79%

<u>DN interviewed students</u>

On the whole, statistically significant gains were posted by the 8 students who comprised the DN interview group. On the measure as a whole, a one-tailed t-test showed significant gains with $p<.01$. A table listing the group's performance is listed below. The mean gain for the DN interview students was 16.7%, with the standard deviation 11.9%. Table 3.9 summarizes the results of the DN interviewed students on each of the relative motion questions.

Table 3.9

DN Interviewed Students' Test Performance

Question	1	3	5	7	9	11	13	15	17	Average
Pretest	75%	50%	75%	0%	75%	62%	38%	38%	25%	49%
Posttest	100%	62%	75%	25%	88%	62%	75%	75%	25%	65%

Interviewed Groups' Prediction Accuracy

Tables 3.10, 3.11, 3.12, and 3.13 detail the accuracy of the predictions made by interviewed students. (In the tables, X represents an incorrect prediction; * represents an accurate prediction that the students did not see as accurate due to "incorrect" direction prediction for 0 speed; - represents no prediction listed on the worksheet.)

Table 3.10

Interviewed Students' Simulation 1 Prediction Accuracy

student	white triangle	grey triangle	black circle	grey circle
AC1 CV			X	
AC2 CV			X	
AD1 CV				
AD2 CV	X	X	X	
AE1 CV				
AE2 CV				
AH1 CV				
AH2 CV				
AA1 DN			X	*
AA2 DN			X	*
AB1 DN	X	X	X	
AB2 DN	X	X	X	
AC3 DN	*	*		
AC4 DN	*	*		
AF1 DN				
AF2 DN				

Table 3.11

Interviewed Students' Simulation 2 Prediction Accuracy

student	X	white triangle	black rectangle	striped rectangle
AC1 CV				
AC2 CV				
AD1 CV				
AD2 CV			X	
AE1 CV				
AE2 CV				
AH1 CV				
AH2 CV				
AA1 DN				
AA2 DN				
AB1 DN			X	X
AB2 DN			X	X
AC3 DN				X
AC4 DN				X
AF1 DN				X
AF2 DN				X

Table 3.12

Interviewed Students' Simulation 3 Prediction Accuracy

student	black triangle	black circle	white circle	grey quad.
AC1 CV			X	
AC2 CV			X	
AD1 CV			X	
AD2 CV			X	
AE1 CV				
AE2 CV				
AH1 CV				
AH2 CV				
AA1 DN				
AA2 DN				
AB1 DN	X	X		
AB2 DN	X	X		
AC3 DN				
AC4 DN				
AF1 DN				
AF2 DN				

Table 3.13

Interviewed Students' Simulation 4 Prediction Accuracy

student	black circle	black triangle	white circle	white triangle	grey triangle	grey quad.
AC1 CV		X				
AC2 CV		X				
AD1 CV		X				
AD2 CV						
AE1 CV					-	-
AE2 CV					-	-
AH1 CV						
AH2 CV						
AA1 DN		*				
AA2 DN		*				
AB1 DN	X	X	X	X		X
AB2 DN	X	X	X	X		X
AC3 DN	X	X	X	X		X
AC4 DN	X	X	X	X		X
AF1 DN	-	*	-	-	X	-
AF2 DN		*			X	

In general, students had little difficulty with the CV simulation activity predictions. Evidence for this is provided by the accuracy of the students' predictions as well as by students' comments on the questionnaire. Several students indicated that the activities were repetitive.

There is evidence that for many, if not all students, the CV condition facilitated visualization during the treatment (see chapter VI for instances). This was expected, as the tasks involved prediction of the direction of travel of objects (for similar results, see Monaghan & Clement, 1994a, 1994b).

Concerning the DN condition, it may be requisite for students to comprehend the meaning of the polar direction in order for visualization to occur. This condition can foster algorithm use; indeed it can foster low reflective algorithm use. However, there is evidence that the DN condition fostered visualization in many cases (see chapter VI).

In examining the students' predictions, it appears that some predictions were clearly easier than others. Indeed, key predictions were intended to foster cognitive dissonance. Specifically, predictions involving objects where direction changed when the frame was changed, and where speed became zero, were intended to foster cognitive dissonance.

In examining posttest results, an improved score on questions 3, 9, and 11 (where direction changes and direction is requested in the problem; possibly also the case for question 1 which is reliant on question 3 for some students) may indicate that the student is able to deal with the dissonance caused by direction change predictions. An improved score on question 17 may indicate the same for the cancellation case.

Many predictions that were expected to cause dissonance were answered correctly by pairs of students. Notably, a prediction that had not been expected to cause dissonance was inaccurately answered by 3 of 4 pairs of DN condition students. In subsequent chapters, case study evidence will be provided that a number of students (if not all students) were using algorithms to come up with their prediction. Algorithm were often employed without visualization (e.g., subject AC4, see chapter VI). Even where one or both students were visualizing during the prediction phase, they often fell into a mode of thinking in which visualization was not employed, either to facilitate completion of the task, or because it was not possible to visualize that component.

Summary

Both the CV honors class and the DN honors class showed statistically significant gains on the posttest. There was not a statistically significant difference between groups' gains scores. In both the classroom and interview studies, DN students made more incorrect predictions during the treatment than CV students. Statistically, DN honors group students made a greater number of incorrect predictions than CV honors group students.

CHAPTER IV

CV INTERVIEW PRETEST/POSTTEST CASE STUDIES

Introduction

In this chapter, selected case studies of interviewed students' performance on the pretest and posttest are described. These case studies are presented to identify the occurrence of learning and to document the type of learning that occurred for individual students following interaction with the CV treatment. (See chapter II for a description of the CV treatment.)

CV Interview Test Results

No statistically significant gains were posted by the 8 students who comprised the CV interview group. Below, table 4.1 summarizes the CV group's performance. The mean gain for the CV interview students was 11%, with the standard deviation 30%.

Table 4.1

CV Interviewed Students' Test Performance

Question	1	3	5	7	9	11	13	15	17	Average
Pretest	50%	63%	88%	63%	88%	75%	88%	63%	38%	68%
Posttest	75%	75%	88%	75%	88%	88%	88%	88%	50%	79%

In table 4.2, the individual scores for the CV interview group are displayed. The pretest combination and posttest combination scores were derived via the following rules.

If the answer is:

- Correct and confidence is "I'm sure ... ," then combination equals +1.0.
- Correct and confidence equals "fairly confident," then combination equals +.75.
- Correct and confidence equals "not very confident," then combination equals +.50.
- Correct and confidence equals "blind guess," then combination equals +.25.

If the answer is:

- Incorrect and confidence equals "I'm sure ... ," then combination equals -1.0.
- Incorrect and confidence equals "fairly confident," then combination equals -.75.
- Incorrect and confidence equals "not very confident," then combination equals -.50.
- Incorrect and confidence equals "blind guess," then combination equals -.25.

Table 4.2

CV Students' Test Scores and Test Gains

Student	Pretest	Posttest	Test Gain	Pretest combina-tion	Posttest combina-tion	Combina-tion Gain
AC1	11%	78%	66%	-.56	.47	1.03
AC2	33%	33%	0%	-.25	-.25	0
AD1	100%	100%	0%	.81	.92	.11
AD2	89%	67%	-22%	.69	.31	-.38
AE1	89%	89%	0%	.56	.75	.19
AE2	44%	89%	45%	-.083	.67	.75
AH1	78%	89%	11%	.50	.75	.25
AH2	100%	89%	-11%	.89	.58	-.31

Below, hypotheses concerning how students may construct mental models of relative motion problems are presented to provide background for understanding case study protocol.

Students' Relative Motion Model Construction

I hypothesize that students often construct a mental model of a relative motion problem through parallel construction of a visual model (see Wiser, 1992) of the problem and a numeric model of the problem. The fabrication of the visual model involves construction of individual components of the model and coordination of those components. (For a similar hypothesis, see Finke, 1989.) I hypothesize that this is done by constructing a visual model of the motion of objects relative to each medium which motion occurs in or on and coordinating the components. In parallel with visual model construction, the student constructs a numeric model of components of the problem and combines those numeric components. The visual model and the numeric model are subject to criticism based on a student's epistemological commitments (e.g., the "true" velocity of an object is its velocity relative to the ground (see Saltiel & Malgrange, 1980). For a discussion of epistemological commitments as a part of the student's "conceptual ecology," see Posner, et al. (1982).) If both the visual model and the numeric model pass the epistemological commitment tests, then they are combined into a resultant mental model. A clash between the interpretation of the problem scenario fostered by consideration of the visual model and the interpretation fostered by the numeric model can cause reconstruction of each model, based on the belief of the student in the accuracy of each model. Additionally, each model can affect the other model, as inconsistencies may be noticed between the representation fostered by one model and the representation fostered by the other model. However, it is also possible that the student will be unconcerned with, unaware of, or unable to resolve inconsistencies between the scene represented via the visual model and the scene represented via the numeric model (see Linn & Songer, 1991; Posner, et al., 1982). In figure 4.1, the processes involved in this hypothesized model construction are shown. Arrows in the diagram reveal potential paths for the flow of mental processing.

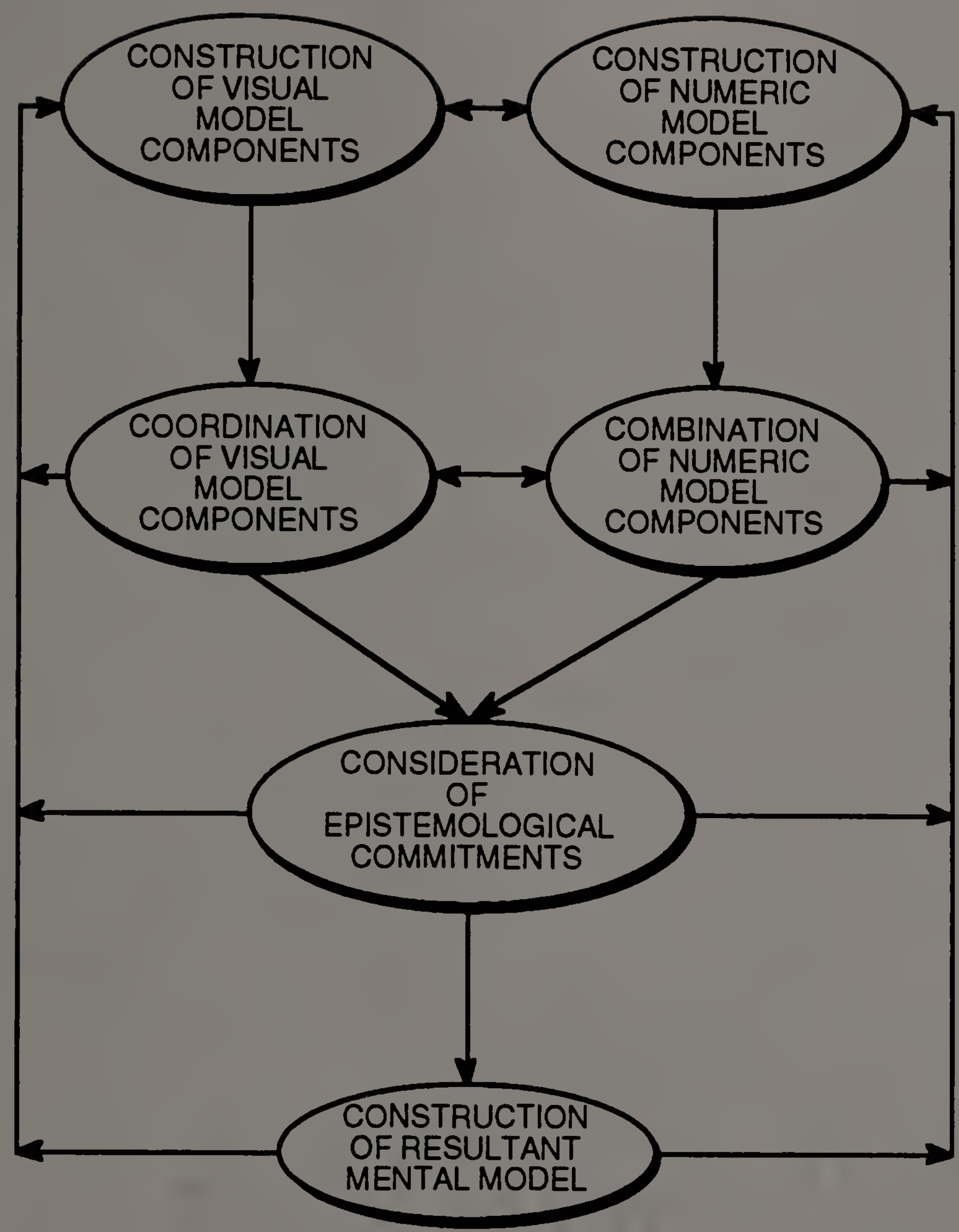


Figure 4.1
Hypothesized relative motion model construction processes

Following are selected protocol and analyses of high school science students involved in the interview studies. Supporting evidence for the hypotheses above as well as general evidence concerning students' problem solving approaches are provided.

AC1 Case Study

In table 4.3, the accuracy of AC1's responses to the diagnostic problems is displayed (1 indicates correct; 0 indicates incorrect).

Table 4.3

AC1 Test Accuracy

Question	1	3	5	7	9	11	13	15	17	Score
Pretest	0	0	1	0	0	0	0	0	0	11%
Posttest	1	1	1	1	1	1	0	1	0	78%

AC1 Pretest

Protocol evidence for difficulties with relative motion pretest problems are displayed below. Student AC1 apparently ignores the effect of the motion of the reference frame on the answers for problems 7 and 9.

> AC1: [question 7--see appendix] If the barge is going to the left at four miles per hour, and the barge worker's walking in the opposite direction, then um, in relation to the, to the cruise ship, the um, barge worker is just staying at the same place. So it's zero miles per hour [correct answer is 10 mph]. Because um, because the barge worker is sort of evening off how far the barge has gotten away from the cruise ship.... I'm fairly confident in my answer.
>
> [question 9--see appendix] The barge worker is walking towards the right, and Joe is facing the bar, barge worker.... To

keep him in his, in the telescope range, then he has to move the telescope to the right [correct answer is to the left], ... with the barge worker.

<u>AC1 Treatment</u>

During simulation activity 1, AC1 expresses surprise with apparently unexpected output of the computer simulation . AC2 appears to assist AC1 in understanding the simulation output, as indicated in the following protocol:

AC1: Why isn't the bike [frame of reference] moving?

AC2: If we're, I would think that if we were in like the focus of, we're on the bike, um, and you're looking down [points down with pen in right hand], we're going [moves right hand to the right] along with the bike so it doesn't look like it's [the bike] going.

AC1: Oh, OK. Right, so then we pass pyramids, and then the dog passes us [moves right hand back and forth].

AC2: The dog passes us.

During the above interaction, both students appear to employ dynamic mental imagery (see Clement, 1994; Finke, 1989), evidenced by hand motions, reports of self-projection, and the report of multiple states of the scenario. I hypothesize that such mental imagery during the treatment may assist students in visualization of relative motion problems when the computer simulation is absent (see Monaghan & Clement, 1994a, 1994b for similar results).

AC1 Posttest

AC1 apparently made substantial gains in her understanding of relative motion. Her posttest score on the 9 question test was 77%, compared with 11% on the pretest. For example, problems 7 and 9 revealed accurate reasoning.

> AC1: [see question 7 in appendix A] Well the cruise ship is traveling to the right--ten miles per hour, and the barge worker's traveling to the right at four miles per hour, but the, um, barge is going to the left at four mile per hour. They'd [barge worker and the barge] both um, even each other off--the barge workers' speed relative to the cruise ship would be ten miles per hour.

Similarly, her answers to several other posttest questions revealed an understanding of relative motion that had not been displayed during the pretest.

Below, she refers to the influence of the computer simulation on her solution.

> AC1: I'm not sure if, if it was like the computer um, where if the um, cruise ship is--the fix thing that--stays still, or that is <u>looks like</u> [emphasis added] it stays still, but it's really going ten miles to the, per hour to the right, then I think the uh, if the ship <u>looked like</u> [emphasis added] it was staying still, then the barge worker would be going ten miles to the left, um, in respect to the ship ... on this [computer] screen or whatever, it's [the cruise ship] stayin' still

Following a very short treatment, AC1 showed substantial gains in her ability to solve relative motion problems; she clearly and accurately transferred experiences with the collaborative simulation activities to transfer problems. It appears that the activities assisted her with visualization, providing a template for her visualization of transfer problems. (For a similar result, see Monaghan & Clement, 1994a, 1994b.) Subject AC1, who made substantial gains on the posttest, was aided in her understanding of simulation 1 by AC2. It is conceivable that the cognitive effort expended by AC1 in her attempt to understand the anomalous data triggered conceptual change (see Chinn & Brewer, 1993; Posner, et al., 1982; Strike & Posner, 1992). However, AC1's partner, AC2, did not display substantial gains, scoring 33% on both the pretest and posttest. It is plausible that this was due to insufficient experience with the collaborative simulation activities. Or, the presented activities were not at the appropriate level for her to advance her current conceptions.

As an example of the model construction process shown in figure 4.1, I present the case of subject AC1's hypothesized model of the scenario described in test questions 7 and 9 (see appendix A for text of the problems).

In her posttest protocol, the student incorporated the movement of the cruise ship (relative to the ground) into her model of the problem. I hypothesize that this was done in part because the student had changed an epistemological commitment which had occurred during the pretest, namely that the motion of the person on the barge is independent of the motion of the motion of the cruise ship. Additionally, it appears that experience with computer simulation activities affected the student's visual model of the problem, as she refers to the cruise ship as equivalent to the still object on the computer screen. This analogous reasoning may indicate improved understanding of the reference frame concept, a necessary prerequisite for accurate mental imagery of the problem. I further hypothesize that critical to, and concurrently developed with, her visual model, is her numeric model of the problem. Without an understanding of the numeric information present in the problem, she would be unable to produce a unique visual model of the problem, thus the contention that the numeric model and the visual model of the problem evolve in parallel.

In her pretest protocol, the student showed an inconsistency between her visual and numeric models of the problem, as evidenced by her responses to questions 7 and 9. Her response to question 7, that the barge worker was traveling 0 mph relative to the cruise ship is inconsistent with her response that the barge worker was moving to the right relative to the cruise ship. In this case, it may be that consideration of the aforementioned epistemological commitment affected her model construction.

Based upon protocol from AC1 and protocol from AE2 (quoted below), I believe that the animation provides an external representation (or model) which often can assist construction of an internal visual model of an event. Furthermore, components of this internal visual model may be applied more generally to other relative motion events For instance, AC2 speaks about the helicopter as like the computer simulation object that did not move. Since the student was not given any numbers from which she could have developed a numerical algorithm, this suggests that her calculation of the answer was informed by visualization of the problem. This analysis appears very plausible in her solution on the telescope problem. The student may not visualize the entire scene at once; indeed, she appears to take a component approach to forming a complete visual model of the target problem event. Apparently, she successfully coordinated components of her visual model into an integrated model which appears to have assisted her numeric solution of posttest problem 7 and her directional solution of the posttest problem 9.

AE2 Case Study

In table 4.4 below, the accuracy of AE2's responses to the diagnostic problems is displayed (1 indicates correct; 0 indicates incorrect).

Table 4.4

AE2 Test Accuracy

Question	1	3	5	7	9	11	13	15	17	Score
Pretest	0	1	0	0	1	1	1	0	0	44%
Posttest	1	1	1	1	0	1	1	1	1	89%

AE2 Pretest

As evidenced by her answers for pretest problems, AE2 seemed to have a reasonably good visual model of many scenarios. In particular, her answers to questions 3, 9, and 11 provided evidence that she understood that the relative motion of two objects has an effect on direction of travel of the objects when viewed from the other's frame. Numerically, however, like subject

AC2, this student gave the same answer (160 mph) for pretest questions 13 and 15. She answered 8 for both questions 1 and 3 She appeared to be in transition in her response to question 17 In general, there was evidence that her visualization of the scenarios was often good, but she did not know how to calculate numeric answers for questions 1, 5,7, 13, 15, and 17. Pretest questions 3, 9, and 11, which required a directional answer were answered accurately. Below, protocol from her solution for pretest questions 1 and 3 is presented.

8 AE2: In questions 1 through 6, Tony and Joe are playing air hockey in a cruise ship's game room. Relative to an observer standing on the ground, the ship is traveling left at 10 miles per hour. Tony just hit the puck toward Joe at a speed of 8 miles per hour relative to the air hockey table. What is the speed of the puck relative to the observer on the ground? Ah--

9 I: Can you say what you're thinking.

10 AE2: I guess how fast the puck is going, is it going toward the observer away from, it's like 8 miles per hour.

11 I: OK, and how'd you get it?

12 AE2: Cause it was going toward the observer on the ground and he's standing still.

13 I: OK.

14 AE2: How confident are you in your answer? Um, I'm not very confident in my answer.

15 I: Why not?

16 AE2: Um, cause the ship is moving. What direction is the puck traveling relative to the observer on the ground?...

20 AE2: The ship's moving to the left so--hmm.

21 I: Can you say out loud what you're thinking about?

22 AE2: The speed of the ship is 10, the speed of the puck is 8, the ship is going to the left, and the puck is going to the right, um, I'd say [my answer is] to the left. How confident are you in your answer? Um, I'd say I'm fairly confident.

23 I: OK, could you say one more time how you got your answer, please.

24 AE2: Um, the ship is going to the left at 10 miles per hour and the puck is going to the right at 8 miles per hour, since the ship is going faster to the left than the puck is traveling to the left the observer....

26 AE2: Joe just hit the puck toward Tony at a speed of 8 miles per hour relative to the air hockey table. What is the speed of the puck relative to the observer on the ground? Um--

27 I: What are you thinking about?

28 AE2: Um, the ship is going 10 miles per hour, and the puck is going 8. Um, I'd say [my answer is] 8 miles per hour.

29 I: How'd you get that?

30 AE2: Um, 'cause the puck is going at 8 miles per hour and the observer's standing still but I don't think it goes any faster because of the boat [emphasis added].

31 I: I'm sorry, what was the last part you were saying?

32 AE2: I don't think it goes any faster because of the boat.

33 I: I see, OK. And how's your confidence in you answer?

34 AE2: Um, I'm fairly confident.

AE2 Posttest

AE2's responses to posttest questions 1, 3 and 5 follow.

22 AE2: Okay. In questions one through six, Toni and Joe are playing air hockey in a cruise ship's game room. Relative to an observer standing on the ground, the ship is traveling to the left at 10 miles per hour. Toni just hit the puck toward Joe at a speed of 8 miles per hour relative to the air hockey table. What is the speed of the puck relative to the observer on the ground? Um--the puck is at eight miles per hour--the ship is going to the left at 10 miles per hour--I'd say--[my answer is] 2 miles per hour--to the observer.

23 I: And how'd you get it?

24 AE2: Um, 'cause the ship was going to the left and the puck was going to the right at a lesser speed than the ship. Um, I subtracted.

25 I: I see.

26 AE2: And I guess I'd be fairly confident in that answer....

32 AE2: Um, What direction is the puck traveling relative to the observer on the ground? Um, I'd say--to the--left. 'Cause the ship is moving faster than the puck. The puck will still be going to the left. And I think I'm sure in that answer. (pause) Joe just hit the puck toward Toni at a speed of 8 miles

per hour. Relative to the air hockey table, what is the speed of the puck relative to the observer on the ground? Um--I'd say 18 miles per hour because it's going to the left and the boat is going to the left. But they're both going at different speeds, so I added them. And--and I'm fairly confident in that answer.

33 I: Okay. And could you say one more time, please, how you got your answer?

34 AE2: Um, 'cause the boat is going at 10 miles per hour to the left and um, the puck is going at eight miles per hour toward the left and I added them.

AE2 Questionnaire

Following the posttest, AE2 provided evidence for the efficacy of the computer simulations in assisting her solutions to ship and car/truck problems. Her retrospective responses, given during the questionnaire phase following the posttest, indicated that memory of the computer simulation activities assisted her solution of numeric problems. Although the evidence is not as convincing as that for subject AC1, because the protocol was given after the problem had been solved, nevertheless, it is an additional case where memory of a computer simulation that had provided only visual feedback, can assist a student's solution of a numeric problem. Combined with the result from AC1, it provides evidence that visualization appears to assist some students with solution of relative motion problems. Protocol from her response to questionnaire items is listed below.

102 AE2: The part of the activities that I enjoyed the most was--I think the computer stuff.

103 I: What part?

104 AE2: Um. Hmm. I guess--hmm. Let's see. Um, working on the computer and working with a partner, like.

105 I: Okay. (pause)

106 AE2: And, the part of the activities that I enjoyed the least was--um, trying to find the answers to some of these questions, I guess (laughs).

107 I: Can you give an example?

108 AE2: Um--like, trying to figure out the speed of something, and it was like, relative to um--like, two other things. (pause)

109 I: Uh, can you give an example of the other things that something was relative to?

110 AE2: Um, the like, to something moving and not standing still, or where you had to take other speeds into consideration. (pause)

111 I: Uh, which one was uh, like that?

112 AE2: Um--like the car and the helicopter [in questions 13 and 15]. (pause)

113 I: I see.

114 AE2: I think the um, the part of the activity that was helpful in solving the problems were--were the visuals. (pause) Did computer simulation activities help you to visualize any of the problems? If you answer yes, please state which problems the simulation helped you to visualize, and why the simulation was helpful. Um, I did think that it helped. Um, it helped me visualize the problems. Um, I think like, with the--the problem

with the barge, or the cruise ship. Whenever there was a ship or a boat, it helped me most with those ones. (pause) Did the computer simulation activities help you to calculate the answer for any of the problems? If you answer yes, please state which problems the simulation activities helped you to calculate answers for, and why the simulation was helpful. Um. I think it did help me to get the right answer for um, the--the problems where two things were moving in opposite directions, such as the helicopter and the truck [in questions 13 and 15]. (pause)

115 I: I'm sorry. Which one did you say?

116 AE2: The problem with the truck and the helicopter.

117 I: Okay. (pause) And why was the simulation helpful on that one?

118 AE2: Um, because it helped me to see how they would move past each other. I could see that in my mind [emphasis added]. (pause)

119 I: Okay, and on the uh--on the previous question uh, why uh, was the simulation helpful?

120 AE2: Um, 'cause I could--I could see [emphasis added] th--the boat moving and I could--I could think of somebody like, standing on it. H--how some things standing still would look [emphasis added] from a boat and how something moving in the opposite direction of the boat would look [emphasis added].

121 I: I see. (pause) Okay. (pause)

122 AE2: Um, your rating of the computer simulation activities. Um, I'd say--I'd say "A." I liked them and I think they helped me out with these questions, too.

Summary

It is somewhat surprising that AE2 dramatically improved her score on the diagnostic test following interaction with computer simulation activities, as she showed few, if any, signs of conceptual dissonance during the activities. Indeed, during the first simulation she appeared to take the lead for a time, though for many of the other simulation activities, her partner appeared to lead. She did appear to agree with him during the activities, however, and based on her interaction with him during the first simulation, both students appeared comfortable with disagreement (she had pointed out that she disagreed with her partner during the first simulation; he ended up changing his position as a result of her insight).

It is plausible that interaction with a more accomplished partner may have facilitated AE2's gains in understanding on the posttest. (AE2's partner, AE1, correctly answered 8 of 9 pretest problems.) This analysis is compatible with Vygotsky's (1978) theory of the zone of proximal development. However, this position is difficult to maintain as she did not apparently show any concern with the predictions that her partner made. Additionally, as shown above, she was the leader when a disagreement occurred during simulation 1.

CHAPTER V

DN INTERVIEW PRETEST/POSTTEST CASE STUDIES

In this chapter, selected case studies of interviewed students' performance on the pretest and their performance on the posttest are described. These case studies are presented to identify the occurrence of learning and to document the type of learning that occurred for individual students following interaction with the DN condition.

DN Interview Test Results

On the whole, statistically significant gains were posted by the 8 students who comprised the DN interview group. On the measure as a whole, a one-tailed t-test showed significant gains with $p<.01$. Below, table 5.1 lists the group's performance. The mean gain for the DN interview students was 17%, with the standard deviation 12%.

Table 5.1

DN Interviewed Students' Test Performance

Question	1	3	5	7	9	11	13	15	17	Average
Pretest	75%	50%	75%	0%	75%	62%	38%	38%	25%	49%
Posttest	100%	62%	75%	25%	88%	62%	75%	75%	25%	65%

In table 5.2, the individual scores for the 8 member DN interview group are displayed. As for the CV interviewed students, the pretest combination and posttest combination scores were derived via the following rules.

If the answer is:

- Correct and confidence is "I'm sure ... ," then combination equals +1.0.
- Correct and confidence equals "fairly confident," then combination equals +.75.
- Correct and confidence equals "not very confident," then combination equals +.50.
- Correct and confidence equals "blind guess," then combination equals +.25.

If the answer is:

- Incorrect and confidence equals "I'm sure ... ," then combination equals -1.0.
- Incorrect and confidence equals "fairly confident," then combination equals -.75.
- Incorrect and confidence equals "not very confident," then combination equals -.50.
- Incorrect and confidence equals "blind guess," then combination equals -.25.

Table 5.2

DN Interviewed Students' Test Scores and Test Gains

Student	Pretest	Posttest	Test Gain	Pretest combination	Posttest combination	Combination Gain
AA1	89%	100%	11%	.56	.83	.27
AA2	22%	33%	11%	-.28	-.14	.14
AB1	11%	33%	22%	-.67	-.17	.50
AB2	56%	56%	0%	-.028	.083	.11
AC3	44%	56%	11%	-.028	.25	.28
AC4	67%	78%	11%	.31	.53	.22
AF1	67%	100%	33%	.50	.92	.42
AF2	33%	67%	33%	-.19	.44	.63

Following are selected protocol and analysis of high school science students involved in the interview studies.

AF1 Case Study

In table 5.3 below, the accuracy of AF1's responses to the diagnostic problems is displayed (1 indicates correct; 0 indicates incorrect).

Table 5.3

AF1 Test Accuracy

Question	1	3	5	7	9	11	13	15	17	Score
Pretest	1	1	1	0	1	1	0	0	1	67%
Posttest	1	1	1	1	1	1	1	1	1	100%

AF1 Pretest

AF1 displayed no difficulty with questions 1 through 5 and he expressed great confidence in his answers. However, question 7 gave him trouble. He thought that the speed of the worker relative to the ship would equal 4+10=14. However, he did not see this answer so he figured that the answer would be 6, i.e., 10-4. His answer on question 9 indicates that he has a visual model that may assist him. His numeric answer for number 7 is not consistent with his response for number 9. As for AC1 (see chapter IV), this may indicate that he has separate numeric and visual models of the problem. In answering pretest question 9, he did not talk about the motion of the barge worker, and only referred to the motion of the barge and the motion of the cruise ship. It is very plausible that AF1 had no way to produce a numeric model for the problem, as suggested by his statement in line 35. Protocol for pretest questions 7 and 9 is displayed below.

29 AF1: [question 7] Joe is watching a barge from the deck of a cruise ship. The barge is being pulled by a tugboat at a speed of four miles an hour relative to the still water. A barge worker's walking towards the back of the barge at a speed of four miles an hour, relative to the barge. The cruise ship is traveling at ten miles an hour relative to the still water. Um--

30 I: What are you thinking about?

31 AF1: I'm just ah, I'm just trying to think exactly how that relates to the diagram. I think I'm all set now. What is the bar, barge worker's speed, relative to the cruise ship. So this is moving ten miles an hour, and this is moving four miles

an hour, so what is the barge workers' speed relative to the cruise ship? Um, um, hum. I'm not sure, I mean, the barge worker is, is moving, and the cruise ship is moving the opposite way, but I don't see fourteen, so it can't be that, um, I'm going to say six miles an hour. How confident are you in your answer? I'm not very confident in my answer.

32 I: Could you say how you got your answer please?

33 AF1: Basically, ah, um, four and ten is fourteen, and that's not an answer here, so the other option would be to go ten minus four which is six. [emphasis added]

34 I: I see.

35 AF1: So, that's probably not the way to go about getting the answer. I don't really know how to do it, so that's what I'm resorting to. [emphasis added]

36 I: Okay.

37 AF1: [question 9] Joe is viewing the large, barge worker through a telescope. To keep the barge worker in the center of his vision, which may, which way must he move the telescope? He must move it to the left. I'm sure my answer is right.

38 I: How'd you get that one?

39 AF1: Because the ship is moving to the right, and the barge is moving to the left, so he has to move to telescope left to compensate for its movement.

For questions 13 and 15, AF1 determined that an algorithm was necessary. He referred to question 7, stating that 7 was easier because it involved smaller numbers. He correctly answered question 13, but then as he answered question 15, he changed his response for question 13. He apparently used an algorithm which could be stated: "add when going same direction; subtract when going opposite directions," as shown in the following protocol:

56 I'm going to say 160 miles an hour [response for pretest question 15], and I'm going to change number thirteen to 240 miles an hour.

57 I: Why's that?

58 AF1: Because I wasn't sure what you do with the other one, I mean whether, in number thirteen whether or not you subtract or add it. Add I th, I think, if they're going opposite directions, then you would subtract, and if you're going the same direction, you would add [emphasis added], but I don't, I don't really know, but. So I'm still not very confident in my answer.

59 I: Okay, so you said opposite directions, sorry?

60 AF1: Opposite directions you would subtract, and same directions you would add, but like I said I'm not sure about that.

He indicated that he was a little bit more sure than blind guess level. He seemed sure that he was either right or that he had the algorithm backwards; indeed from his responses to questions 13 and 15, he did have the algorithm backwards.

Pretest question 17 did not appear to pose serious problems for AF1. He reasoned that the speed of the truck would counteract the speed of the ball. It appears that he did visualize the problem and that he also seems to have an accurate numeric model for the problem. However, he was not very confident in his answer.

Additionally, his correct reasoning on this problem could be seen as inconsistent with his reasoning on pretest questions 15 and 13. Protocol from his solution for pretest problem 17 follows.

68 AF1: Well, I'm just <u>trying to picture this</u> [emphasis added], ah, and I'm going to say it's going to fall and hit the ground at "P" [correct answer]. Um, just because, I mean, the, the two speeds are equal, and they're both going different ways which would mean that it'd average out to be right where he throws it....

70 AF1: But I'm not sure about that, so I'm not very confident in my answer.

<u>AF1 Posttest</u>

AF1 showed improvement on questions 7, 13, and 15 and improved his confidence on number 17. It is very possible that interaction with the computer simulation activities affected algorithms used by AF1. (See chapter VI for protocol describing AF1 and AF2's use and modification of algorithms during the treatment.) Protocol from posttest questions 7 and 9 are below.

26 AF1: [see question 7 in appendix] OK, the barge is moving 4 miles an hour, and he's moving 4 miles an hour back which means that he's moving, basically he's staying in the same place and so he's not <u>really</u> [emphasis added] moving, so the cruise ship is going to be moving 10 miles an hour, so what is the barge worker's speed relative to the cruise ship? Because the barge worker's not moving and the cruise ship is moving along at 10 miles an hour, it's [the answer is] going to

be 10 miles an hour. Um, yeah it's going to be 10 miles an hour. Um, yeah OK, and I'm sure my answer is right, OK.

27 I: ... what were you thinking about?

28 AF1: ah, I just, I got all confused because I'm pretty tired today, ah, what relative, what that was trying to imply, and so um, what is the barge worker's speed relative to the cruise ship? The cruise ship if it was going no miles, I mean if it was staying there, which is what it's going to be doing, he's going to be going 10 miles an hour [emphasis added--possible reference to computer simulation where the object that defined the frame of reference had 0 velocity].

29 I: I see.

30 AF1: (question 9) OK, Joe's viewing the barge worker through a telescope. To keep the barge worker in the center of his vision which way must he move the telescope? To keep the barge worker--ah. Wow, ha OK, um, he's going to have to be moving to the left, and I'm sure my answer's right.

31 I: Could you say how you got your answer?

32 AF1: Ah, if he's looking up through the telescope and he's going and sorry the ship is going 10 miles to the right, and even though the barge worker won't be moving um, as far as it'll, it'll be the same speed as the water which is nothing. So, even though he's not moving he'll still, the ship is still moving 10 miles an hour, so he'll have to compensate by moving [the telescope] to the left.

He used an accurate algorithm in solving 13 and 15. Protocol from his posttest answers for 13 and 15 follows.

36 AF1: [question 13] In the picture above you are in the gray car; your speedometer reads 40 miles an hour. What is your car's speed relative to a very low flying helicopter? Relative to the ground, the helicopter is going exactly the same direction as your car, at a speed of 200 miles an hour. So the helicopter's going this way at 200 miles an hour--OK, ah, what is your car's speed relative to a low flying helicopter? Um, you're going to be going 160 miles an hour, and I'm fairly confident in my answer.

37 I: How'd you get it?

38 AF1: Because, um, if the if the helicopter is moving along at 200 miles an hour, and you're going 40, then he's going to be going um 160 miles an hour faster than you but if you take that into, if he's, if you're, if the car is relative to the helicopter that means that you'll be going 160 miles an hour faster--I think.

39 I: I see.

40 AF1: [question 15] The white truck is traveling toward your position. If the truck's speedometer reads 40 miles an hour what is the truck's speed relative to the helicopter? Um, now it's going to be going 40 miles an hour the opposite way, so it'll end up being 240 miles an hour. And I'm fairly confident in my answer.

41 I: Why not positive?

42 AF1: Well for the same idea, well um, because I'm not 100% sure I've got ah, you know the principles quite right, but if the same holds true for number 14 then 15 will be right, so.

43 I: OK what principle are you concerned about?

44 AF1: Um, when they're going the opposite direction, towards, you know going towards each other, I think it's going to be added [emphasis added] to um, but I'm not positive.

As on the pretest, during the posttest, he correctly answered question 17. His reported confidence in his posttest answer is greater than his reported confidence in his pretest answer, as shown below.

45 AF1: [question 17] Ah, I'm going to say fall and hit the ground at P, [correct answer] and that's because if the truck is going to the left at 40, and he's going to throw a snowball at 40 the opposite way, they're both going to compensate for each other and it'll just go plop on the ground. So, I'm sure my answer is right.

46 I: Positive?

47 AF1: Yes.

48 I: No doubt in your mind?

49 AF1: Well, a little.

50 I: What's the doubt?

51 AF1: Well, I, I mean it's the same thing, um as the last question. They're both going opposite directions. The truck is going to go the opposite direction as the snowball, and I'm not sure, you know, the principles, so maybe I'll mark C [fairly confident].

Summary

Evidenced by his performance on posttest questions 13 and 15, AF1 appears to have advanced in his ability to solve numeric relative motion questions. It appears that he used an accurate algorithm when solving posttest problems 13 and 15; in contrast to the faulty algorithm applied to pretest problems 13 and 15. It is plausible that this advance was caused by interaction with the computer simulation activities, as a similar algorithm to the one applied to posttest questions 13 and 15 was expressed during the treatment (see chapter VI). AF1 increased his confidence in his accurate answer to question 17. During the posttest, unlike the pretest, the numeric solution for question 7 was consistent with the directional solution for question 9, suggesting that during the posttest, numeric and visual models constructed by AF1 for questions 7 and 9 were compatible.

AF2 Case Study

In table 5.4 below, the accuracy of AF2's responses to the diagnostic problems is displayed. (1 indicates correct; 0 indicates incorrect)

Table 5.4

AF2 Test Accuracy

Question	1	3	5	7	9	11	13	15	17	Score
Pretest	0	1	1	0	0	1	0	0	0	33%
Posttest	1	1	0	0	1	1	1	1	0	67%

AF2 Pretest

During the pretest, there is evidence that AF2 clearly reasoned and was rather close to accurate in his answer for question 1. He apparently showed close but faulty reasoning on questions 13 and 15, and appears to have reasoned accurately on question 11.

He also reasoned accurately on question 3--indicating that he was accurately able to visualize the scenario. During the pretest, there is some question whether the student understands the term relative to--indeed, there is evidence that he had difficulty understanding the term. His answer was fairly accurate on question 9 (telescope question).

AF2 Posttest

Based on protocol given during the posttest, student AF2 appears to have developed algorithms for calculating relative speeds, one algorithm being that when objects are approaching, you add the speeds, when objects are going the same direction, you subtract the speeds. He also appears to have developed a (faulty) algorithm for determining the direction of travel, namely, that when two objects are going the same direction, the faster one will look like it is traveling the opposite direction. In the following, he states an algorithm for determining relative speeds. Like other students, before the posttest, he was told that I was interested in seeing whether the using the computer simulations helped him solve any problems (see Holyoak, 1991 for a discussion of how this statement may affect the student's reasoning). Following this statement by the interviewer, there is evidence that he attempted to map features of his memory of the simulations onto posttest problems. Evidence for one such attempt at mapping is contained in his response to question 1.

8 AF2: Okay. In questions one through six, Tony and Joe are playing air hockey in a cruise ship's game room. Relative to the observer standing on the ground, the ship is traveling to the left at ten miles per hour. I'm gonna write ten, left. Tony just hit the puck toward Joe at a speed of eight miles per hour relative to the air hockey table. So Tony hit it right at eight miles per hour. What is the speed of the puck relative to the observer on the ground? The observer on the ground is still not moving. When I was doing the computer simulation, if there was like a black, a black circle going left at 180, and the white circle going right at 180 and you were looking at say, something say, a square, if you were looking at a square, that would be zero, zero, or zero to the right [emphasis added]. So the black circle in this case would be going eight miles per hour because that's the puck. The white circle, going left, would be the boat going ten. So, and the observer would be the square.

9 AF2: What is the speed of the puck relative to the observer on the ground? Um, the speed, okay let me think, the speed of, when I was doing the opposite of the computer simulation it was, you change the fo--when the focus changes, the speeds change. But here the focus, the, the point that you're ah, focusing in on, or I forgot what it was called in the computer simulation, but, it was, you change the ah, the the, the, the, the main focus was the observer. And in this case it's, it's the observer, and it's not changing. So, I still, I still believe that it's two miles per hour. Uh. And I'm fairly confident in that.

10 I: How'd you get your answer?

11 AF2: I could--when I was, the thing, I could, I had trouble relating the computer simulation to this simulation. Because here I see the, the puck is on the boat. And ah, in the computer simulation the square was never on, like, the black circle wasn't on the white circle. So, when I see the puck is on the boat, I, I assume that the boat's speed cancels out most of the puck's speed. Would it be two? Or would it be, um-- No, I'd s, no, it's not two. It would be, the boat's speed cancels out all of the puck's speed, so it'd be zero. I don't see how, I'm still fairly confident in the answer of zero, I've changed that. But <u>I don't see how the computer simulation actually relates, to ah, to this, because in the computer simulation, the black circle was never on top of the white circle</u> [emphasis added]. There were two different entities, and here the, the puck is on top of the boat. And if the boat is going faster in the opposite direction, it'll appear that the puck is not really moving. It'll only appear if the puck is moving left, but it won't be moving left at ten, it'll be moving left at two. So if this is two miles per hour left, if, if question one, the question one the first part is two miles per hour left, then I agree with that, because that's also negative two to the right. Cause if that's, then it, then in that case I'd say it's two, because it's two miles per hour left because the boat's actually going faster than the puck.

12 AF2: But the puck wouldn't appear to be going ten miles per hour because it's, because eight, eight miles per hour of the ten is going right. That's what I'm, so if that's two miles

per hour left, then I'll circle that. I wrote, I wrote left in there, and with that proviso, I'm completely sure that it's right. So what I was thinking before, I was thinking, two miles per hour, I was thinking how fast would the puck be going right, but the puck can't go right if the boat is going faster than it....

15 I: Okay so, I'm sorry, so you said zero before?

16 AF2: I said zero before, but I changed it to two, as long as it's going left. And number three says what direction is pucks, is a puck traveling relative to the observer on the ground? Before I said neither to the left nor right, but now I say to the left.

17 I: And how'd you get your answer?

18 AF2: Um, I'm, because the boat is going ten to the left, and if you ss, and the puck is going eight to the right. Before I thought it was zero miles per hour, because um, I thought it was zero miles per hour, neither to the left nor the right because I thought ah, that it wasn't moving, it wasn't moving at all because the boat being ten canceled out the eight. But now that I see that, when I, after the computer simulation it actually did help me, I see that the, the puck is going negative two to the right, which by looking at the relation on the computer simulation is actually positive two to the left [emphasis added]. So that's why I got a different answer for one and three.

19 I: I see.

20 AF2: Um, um, I'm sure that that's right. Either that or, I'm sure because on the computer simulation, I got the

answers. So, I, I, I learned the sort of formula in my head [emphasis added], or the how to work the problem out....

22 AF2: I'm sure that it's right because I saw, I saw in other problems similar to this one on the computer that the computer's setting it right, and I put my faith in the computer [emphasis added].

In his response to posttest question 5, AF2 articulates his (faulty) algorithm for determining the direction of travel of an object when viewed from a non-ground frame of reference.

22 AF2: So the puck is, the, the boat is going faster than the puck. So actually, from the computer simulation, I actually think that um, the puck would appear to be going to the right. Two miles per hour to the right. Because ah, because it was because what I was explaining to, trying to explain to-- [his partner, AF1]. I don't, I don't even know if I really understood it at the time. That, when there's something going, there's two things going in the same direction, if one thing, if one entity is going faster than the other, then it will appear in ah, if you put it in space, if you put in space, it would appear that the one that's going slower is actually going the other way. It would appear to another entity looking on. It would appear that the oth, that slower one is going the other way than the faster one [emphasis added]. But really all that's happening, is ah, they're both going the same way except one is going b, ah, a speed that's increasing. So, I'm fairly, I'm confident, fairly confident in my answer.

30 AF2: I said two because that's two to the right. Because th, the puck would appear to be going right, because the boat is going fa, they're both going left, but the boat is going faster to the left. So, they're both going left, but the boat is going at a faster speed, so if you look it would appear that ah, the puck is going the other way, 'cause the boat is out-distancing it.

Summary

It appears that AF2 attempted to map features of the computer simulations onto posttest problems. There is evidence that AF2 successfully used an algorithm to calculate relative speeds during the posttest. Additional evidence indicates that AF2 used a faulty algorithm to determine relative direction. Protocol given by AF2 during the treatment provides evidence for use of, and possibly the development of the algorithms applied by AF2 during the posttest (see chapter VI).

AC3 Case Study

In table 5.5 which follows, the accuracy of AC3's responses to the diagnostic problems is displayed (1 indicates correct; 0 indicates incorrect).

Table 5.5

AC3 Test Accuracy

Question	1	3	5	7	9	11	13	15	17	Score
Pretest	1	1	1	0	0	1	0	0	0	44%
Posttest	1	1	1	0	1	1	0	0	0	56%

AC3 Pretest

Below, AC3's responses to selected pretest questions are contrasted with his responses to posttest questions.

Below are his responses to pretest questions 1 through 5.

14 AC3: OK. In questions one through six, Tony and Joe are playing air hockey in a cruise ship's game room. Relative to an observer standing on the ground, the ship is traveling to the left at ten miles per hour. Tony just hit the puck toward Joe at a speed of 8 miles per hour, relative to the air hockey table. What is the speed of the puck relative to the observer on the ground? Zero mi--miles per hour, five miles per hour, two miles per hour, 18 miles per hour, or eight miles per hour. Um, the ship is traveling at ten miles an hour relative to an observer standing on the ground. Umm, and it says that Tony just hit the puck towards Joe at a speed of 8 miles per hour, and so it's the air hockey table--it's relative to the air hockey table which is, um--inside the ship it won't be moving, but outside the ship, it's going about ten miles an hour, so the speed of the puck relative to the observer on the ground is ten miles an hour plus eight miles an hour because it is 8 miles an hour inside the ship, and the ship is moving at ten miles an hour, so it has to be eighteen miles an hour, which is [answer] "D." And, um, I am fairly confident in my answer.

15 I: OK, why not positive?

16 AC3: Ah, because, the--there could be, um conditions in the ship that I don't know of--I don't know....

20 AC3: What direction is the puck traveling relative to the observer on the ground? Um, well the ship is going left, and the puck is inside the ship. Um, but, it doesn't say which, which direction the puck is going on the inside of the ship. So, I would answer neither to the left, nor to the right. Because you don't know which direction the puck is actually going, if was hit to the right or left. So I'm going to say [answer] "C," but I think that--I think that my answer might be just a blind guess, because, it could be going to the left, also, but, I don't know that. I don't, I don't--I haven't really been given much information in this problem, so I'm going to answer "A." Um, Joe just hit the puck toward Tony at a speed of 8 miles an hour relative to the air hockey table. What is the speed of the puck relative to the observer on the ground? Well, it's just--it's--Joe hits the puck to Tony at 8 miles an hour, and the observer is watching the ship go by at ten miles an hour, I think that--hmm--I think that it's "D" also because, because it, it it's the puck we--went 8 miles an hour and the ship went ten miles an hour, and ten plus eight is 18. Um, I think I'm just gonna answer "C" just like the other that I'm fairly confident in my answer because, um, I don't know exactly if it's right or not, but it's, it's, it's it's somewhat right. I don't know, don't know how to explain it.

Following the pretest, the interviewer asked AC3 if he wanted to go back to any questions. Protocol follows.

51 I: OK. Are there any of them that are bothering you that you'd like to go back to?

52 AC3: Um, there's--yeah, this--the first one.

53 I: OK.

54 AC3: I didn't read the question [number 1] right. Um, but it's--Toni just hit the puck toward Joe at a speed of 8 miles per hour. Um, so I was thinking it was going in the opposite direction, but it's not. So, it would be, um, it would be 2 miles per hour, not 18, because, um, because the--the ship is traveling 10 miles per hour, and he's hitting, hitting the puck towards Joe at a speed of 8 miles per hour, so the difference would be, um, 2 miles per hour. I think, I think that's right.

55 I: OK, how had you read the question before?

56 AC3: Well, I, I had read the question that, um, I was just thinking that the puck was traveling in the same direction as the ship. I didn't mean that Toni had just hit the puck, um, and, that messed my answer up, because um, there was, the, the ship was going ten miles per hour, and the puck was going at 8, so I assumed that it would be 18, but, um, the puck is going in the opposite direction as the ship. So, it must be 2 miles per hour.

As question 3 depended on an understanding of question 1, the interviewer asked AC3 to consider his answer to question 3.

63 I: OK. If I could, ah, could you just check number three, because I think three depended on number one.

64 AC3: Toni hit the puck toward Joe. OK--oh, the puck is going 2 miles per hour relative to the ground, and in what direction is the truck--is the puck--traveling relative to the observer on the ground? Oh, OK--well, then, if the puck is

going 8 miles per hour, then the--it would be going to the left instead of neither to the left, nor right. Because, the um, ship is going faster than the puck is traveling in the opposite direction. Um, so, even though the puck is traveling--is traveling--traveling right 8 miles per hour, it would appear to be the observer on the ground as traveling to the left at 2 miles per hour, so, I'll say, "B." and I'm going to change my confidence on that one to "D."

65 I: OK, are you sure?

66 AC3: Because, because the--the um--the puck is being shot at Joe at 8 miles per hour, and the ship is traveling at 10 miles per hour, so it would appear to an observer as going 2 miles per hour to the left, because the ship has more initial, um, momentum than the puck does because it's going faster, and I think that it--it would be, um, I think that my answer is right.

In the above protocol, it appears that AC3 is aware of the effect of the medium's speed, relative to the ground, on the speed of the supported object, relative to the ground.

In the following protocol, AC3 appears to have difficulty with pretest questions 7 and 9.

22 AC3: Numbers 7 through 10 refer to the scene described below. Joe is watching the barge from the deck of the cruise ship. The barge is pulled by a tugboat at a speed of 4 miles per hour, relative to the still wa--water. So, umm--a barge worker is walking toward the back of the barge at a speed of 4 miles per hour relative to the barge. The cruise ship is traveling at 10 miles per hour relative to the still water.

Umm, What is the barge worker's speed relative to the cruise ship? Umm, let's see, the barge worker is traveling at 4 miles per hour relative to the barge, and the barge is being pulled at 4 miles per hour, so I think the would be going at the same miles per hour, relative to the still water, each--the worker and the tugboat-- The cruise ship is traveling at 10 miles per hour relative to the still water. So, obviously, the cruise ship is going faster than the barge worker. Um, the barge worker is going 4 miles per hour, and the cruise ship is going 10 miles an hour, so I think, I--I'm just going to guess 4 miles an hour for number seven. Um, wait--um, actually, four--the barge worker is going 4 miles an hour, and the ship is going 10 miles an hour, so that that means there's a 6 mile per hour difference between the two, so I think that--the barge worker's speed relative to the cruise ship, um--no I'll just go with four because--I'll just go with four, um, I'm fairly confident in my answer because, um there there is, um I think that the barge worker's obviously going 4 miles per hour and the cruise ship is going 10 miles per hour, so you know the barge worker's speed is four miles per hour. [Correct answer is 10 miles per hour.] Ah, OK, uh, Joe is viewing the barge worker through a telescope. To keep the barge worker--

23 I: Oh, I'm sorry, what was your confidence on that one?

24 AC3: Ah, I said I was fairly confident.

25 I: OK, and why not positive on that one?

26 AC3: Because, I don't--the, the barge worker's speed is four, but the cruise ship is--is 10, and I don't know how to

exactly say that they're relative because it'd be four to ten, that--that's not six, and I just said four. Because the barge worker's going four and you know that. That much, and I can't--I can't really make an assumption. Um, Joe's viewing the barge worker through a telescope. To keep the barge worker in the center of his vision, which way must he move the telescope? Um, let's see, the barge--keep the barge worker in the center--of his vision--what way must he move his telescope? Well, um, see, Joe is watching the barge from the deck of the cruise ship. OK, so, and according to this, the--according to the picture, the barge is, is being pulled to the left by the tugboat, and, Joe is the cruise ship is going to the right, so that means, according to the picture, they're almost lined up, but, I think that, um, to keep the barge worker in the center of his vision, um, I don't think he has to move his telescope at all. [Correct answer is to the left.] Because the tugboat is moving to the left, and the barge worker is moving to the right, and if they're going at the same speed, then they're they're just um, staying in the same place, because the two speeds cancel each other out, ah, because, if there's an equal pull on both sides, so it's just gonna stay in the same--the barge worker's gonna stay in the same place in his telescope, so I think he should--neither--move his telescope neither way. And I am sure that my answer is right. Because, that--the two are going in both opposite directions, and there's an equal pull. Equal miles per hour.

27 I: I'm sorry, what's an equal miles per hour?

28 AC3: Um, the barge worker and the tugboat are going the same miles per hour.

In the above transcript, AC3 shows an apparent mismatch between his numeric and visual representations of the problem. In the following transcript, AC3 shows signs of algorithm use during his solution to pretest problems 13 and 15.

36 AC3: Ah, Numbers thirteen to sixteen refer to the picture below. In the picture above, you are in a gray car. Your speedometer reads 40 miles per hour. What is your car speed relative to the very low flying helicopter--to a very low flying helicopter? Relative to the ground, the helicopter is going in exactly the same direction as your car at a speed of 200 miles per hour. Um, what is your car speed relative to the very low flying helicopter? Well, the helicopter is going in the same direction as the car, so it's going 200 miles per hour, and the speedometer reads 40 miles per hour, so, I think that--the--I think that it--the car is going--its speed relative to the low flying helicopter is 160, because, the um, the helicopter is going 200 miles per hour and the speedometer reads 40 miles per hour, so the difference would be the--the car to the helicopter would be 160. Um--no, I'm fairly confident in my answer, because, um I don't--I think that relative--when it's relative to the um, when the car is relative to the helicopter, that it would be 160, but I'm not sure if I'm exactly right, because, um, I'm not sure how--if I did the um comparison right, ah--

37 I: Could you say some more about that?

38 AC3: Ah, well, the, the hundred and um, sixty miles per hour--well, I think that, I think that they're going--they're both going in the same direction, and, the speedometer is reading 40 miles per hour and the helicopter is going 200 miles per hour, but I don't know if the, how, how to uh, find out what the car's speed relative to a moving object is. I think that it's 160 because you take the difference of the 200 and 40, um, that's that's, that's my, um, I'm fairly confident because that's--I think that's what you do when there's two moving objects and you take the relative speed to each other [emphasis added]. Um, the white truck is traveling toward your position. If the truck's speedometer reads 40 miles per hour, what is the truck's speed relative to the helicopter? Um, the truck is, reading 40 miles per hour, and the helicopter is going 200 miles per hour in the opposite direction, um, so, uh, I, I, I, the, so obviously, the helicopter will be going, will be going less than--because the truck is going in an opposite way and the truck--that would mean it would be subtracting forty again. Um, I, I think that it'd be a hundred sixty also, but, I think that I'm not very confident in my answer because, um, I don't know how, um, to do the problem with, ah, true--an object going the opposite direction as another object, what the relative speed would be to--for moving objects, um, I don't know. I'm just gonna go on to the next one.

39 I: OK, you said it, ah, I'm sorry, you said it's obviously going to be, ah, less, and I, I didn't catch the rest of that.

40 AC3: Oh, um--

41 I: You said because it's going in the opposite direction as the--

42 AC3: Yeah. Because.

43 I: Could you say some more about that?

44 AC3: Cause, ah, ah, the helicopter is, is traveling 200 miles per hour, and the truck is traveling at 40 miles per hour. The opposite direction, so the relative speed of the helicopter to the truck would be um, the helicopter's speed minus the truck's speed because the truck is traveling in an opposite direction. [emphasis added] Um, so, I just said it was a hundred sixty again. But I'm not--sure.

Later, when asked if he wished to go back to any problems, he reconsidered his pretest response for question 15.

57 I: OK. Any others that you were concerned about?

58 AC3: Um, yes, it says, " In the picture above, you are in a gray car. Your speedometer reads 40 miles per hour, ah, what is your car's speed relative to a very low flying helicopter?" Um, well, the helicopter is going, is going in the same directions your car. So, and, so they're not going in opposite directions, so you're not going to subtract. Which I did, so the car's going 40 miles per hour, the helicopter's going 200 miles per hour, then, the you would, it would not be a hundred sixty. Because, they're going in the, um, same direction. So, it, it would just be about--I'--I'm just guessing forty miles per hour. Because, the car, because they're both going in the same direction, and they're--so the car is 40 miles per hour relative to the ground. And, it can't be 160 miles per

hour because the car is not going 160 miles per hour [emphasis added]. So--um--so the car's speed relative a very low flying helicopter--the car would be going 40 miles per hour, according to the helicopter, which is going 200 miles per hour. So, I'm going to change that to [answer] "A," forty miles per hour. Instead of [answer] "B," because they're going in the same direction. And it would appear that the car would be going slower from the helicopter at 160 miles per hour [emphasis added].

In reconsidering his pretest response to question 15, it is possible that AC3 questioned the applicability of the algorithm previously used to solve the problem. In the above response, he draws a distinction between the speed that the car is going (relative to the ground) and the appearance of the car relative to the helicopter's speed. The above response is contradictory to his pretest response to question 13 where he reasoned that to get the relative speed of two objects you subtract the speeds of the objects (see line 38 above). The hypothesis that AC3 does not understand the term "relative to" is consistent with this data. Also consistent with this data is the hypothesis that AC3 believed that 40 miles per hour was the car's "true" speed and 160 would be its apparent speed (see Saltiel & Malgrange, 1980).

AC3 Posttest

In his response to posttest questions it is possible that he refers to an algorithm which he used during the treatment, as shown in the following transcript.

17 AC3: In questions one through six, Toni and Joe are playing air hockey in a cruise ship's game room. Relative to an observer on the ground, the ship is traveling to the left at ten miles an hour. So that would be the ship pulling away from, from the observer. Toni just hit the puck toward Joe at a speed of eight miles per hour. OK, so Toni hit the puck towards Joe. OK. Um. Relative to the air hockey table. So that would mean that the puck is pulling--is going towards Joe, um, and pulling away from the air hockey table. What is the speed of the puck relative to the--the observer on the ground? Um, well the ship is pulling away from the observer on the ground at--to the left at ten miles per hour, and inside of the ship, the air hockey puck is pulling away from the table, towards Joe at eight miles per, what is the speed of the puck relative to the observer on the ground? The ship is moving to the left at ten miles per hour, and the--puck inside is moving to the right at eight miles per hour, so, the speed relative to the observer on the ground would be two miles per hour, because the ship is traveling ten miles per hour and the air puck is going in the opposite direction at eight miles per hour, so it would be eight minus two, which is two miles per hour, um, that would be the speed of the puck relative to the observer on the ground. How confident are you in your answer? I'm sure that my answer is right.

18 I: No doubts at all?

19 AC3: Nope.

20 I: OK.

21 AC3: What direction is the puck traveling relative to the observer on the ground? Well, since the ship is traveling to the left at ten miles per hour, and the puck is traveling to the right at eight miles per hour, um, it--the puck would not be traveling to the right at, um, because, the, because, because the ship is going faster--its momentum is greater, is greater in one direction than the puck is in the opposite direction. So, to the observer on the ground, everything is traveling to the left, um, so, I would say to the left. Um, How confident are you in your answer? I'm sure that my answer is right--Joe just hit the puck toward Toni at a speed of eight miles per hour relative to the air hockey table. So Joe just hit the puck toward Toni, so it's going in the same direction as the ship, relative to the air hockey table. The puck is traveling at a speed of eight miles per hour, and the ship is traveling at a speed of ten miles per hour. So, speed of the puck relative to the observer on the ground. Well, the sp--the--the ship is going ten miles per hour, so the ship would, would be going fast, while Joe just hits the puck towards Toni, so they're going in the s--so the puck's going in the same direction as the ship. Um, so, I'm guessing eighteen, because the ship is traveling at ten miles per hour, and the puck is traveling at eight miles per hour, so it'd be ten plus eight because they're going in the same direction, so, I'm going to say eighteen miles per hour. Um, and I'm fairly confident in my answer. <u>I'm not sure because, when they're going in the same direction, I think you add</u> [emphasis added] [possible reference to algorithm used during the treatment],

but, they--it might be a little too high. The answer might be a little too high, it might be--lower, I'm not sure.

22 I: OK, could you say some more about that?

23 AC3: Um, well, the, the puck is traveling to the left at eight miles per hour, and the ship is traveling to the left at ten miles per hour, so I believe you would add the two because the puck is traveling in the same direction as the ship [emphasis added]. I believe you would add ten plus eight. Accord--relative to the observer on the ground, but, umm, I'm not sure if you would add eight to ten, um, because, it--it might be--that might be going, that might be a little too fast, relative to the observer on the ground. Um, might be a little too high in miles per hour.

24 I: OK, ah, and your reasoning on that one was?

25 AC3: I'm fairly confident in my answer.

26 I: and I'm, I'm sorry, how'd you get your answer.

27 AC3: I added the speed of the ship, a, ten miles per hour plus the speed of the puck at eight miles per hour to equal eighteen miles per hour.

28 I: OK, why did you add?

29 AC3: Because they were traveling in the same direction, so the speed would, not decrease, it would probably increase. [emphasis added]

During the posttest, he apparently made gains in his understanding of problems 7 and 9. As on the pretest, his numeric and visual representations were not compatible, but the faulty numeric representation may be due to an epistemological commitment that the earth (or sea) is the default frame of reference; or, possibly, he inadvertently changed default reference frames.

33 AC3: OK, numbers seven to ten refer to the scene described below. Joe is watching the barge from the deck of the cruise ship. OK, so Joe is on the ship, and, he's watching the barge. OK. The barge is being pulled by a tugboat at a speed of four miles per hour relative to the still water. OK. A barge worker is walking toward the back of the barge at a speed of four miles per hour relative to the barge. The cruise ship is traveling at ten miles per hour relative to the still water. What is the barge worker's speed relative to the cruise ship? Well, the tugboat is pulling the barge at a speed of four miles per hour relative to the still water. So--and the barge worker is walking toward the back of the barge at the same speed--four miles per hour, um, that's relative to the barge. Um, but, um, is the barge worker walking in an opposite direction, um, so, and the barge is going four miles per hour to the left, um, so I think--and Joe is going ten miles an hour to the right. Um, so, the barge worker is going zero miles per hour relative to the still water because the speed of the barge is, um, four miles per hour, while the barge worker is walking at a speed of four miles per hour, so the two would cancel each other out, but the cruise ship is traveling at ten miles per hour, and if the barge worker, um, is going zero miles per hour, and the ship is going ten mi--the ship would--say the ship is going ten miles per hour, um, so, the barge--hmm. Well, the barge is, is going four

miles per hour, relative to the still water, and the worker is walking four miles per hour relative to the barge, so, the barge would be going--um, well, I'll guess, um, six miles--no, I'll guess four miles--no, um, I'll guess zero miles per hour. Because the ship is going ten miles, ten miles an hour, and the barge worker and the barge are going four miles per hour in the opposite directions, so, according to Joe, um, the barge, and the barge worker would be going zero--the barge worker's speed relative to the cruise ship would be zero miles per hour, um, because Joe is going much faster than the barge and the barge worker, so it would appear that they would going zero miles per hour.... Um, I am not very confident in my answer because, um, I think that zero miles per hour would be much too low, for the, um, barge, barge worker's, um, speed, in comparison to Joe, cause, I don't think--I'm not sure if--if the speed of four miles per hour in both directions--I'm not sure if those two cancel each other out, and they equal zero, cause, um, it might, it might, um, might not cancel that much out, there might be like, two miles per hour for the speed of the barge worker, um, so, and like, and if the cruise ship is going ten miles per hour it might be eight miles per hour, but it could be zero also because the barge worker wouldn't appear to be moving at such as a fast speed as Joe's watching, um--OK. Joe is viewing the barge worker through a telescope. To keep the barge worker in the center of his vision, which way must he move the telescope? Um, OK, so he's view--Joe is viewing the barge worker. Um, so the--the barge worker's speed relative to the cruise ship would be zero miles per hour, so, he--the barge worker would be staying in the same place according to Joe, um, and, so, ugh, to keep the barge worker in the center of his vision, he would have to move the telescope to the left, because the--the barge worker is stationary, and the cruise ship is still moving app--appears to be moving faster than the barge worker is moving. So, the barge worker would still be in his left, um, would, would have to--the telescope would have to be moved to the left. Um, to keep the barge worker in the center of his vision, and I'm sure that my answer is right. Because the barge worker is moving zero miles per hour, and the--cruise ship is moving at--the, the barge worker appears to be moving at zero miles per hour, and the cruise ship appears to movie--to be moving much quicker, so the barge worker would be staying at the same place. But, Joe would be moving more and more to the right, because the cruise ship is going much faster, so the barge worker be--would be more and more--moving more and more to the left, so he would have to move his telescope more and more to the left to keep the barge worker in the center of his vision.

I: And what was your confidence on that?

AC3: I'm sure that my answer is right.

Below, AC3 answers posttest problems 13 and 15. He explicitly states that he did not use a formula to get his answers.

37 AC3: Numbers thirteen through sixteen refer to the picture below. In the picture above, you are in a gray car.

Your speedometer reads forty miles per hour. OK, so it's going forty miles per hour--OK. What is your car speed relative to a low flying helicopter? To a very low flying helicopter? Um, Relative to the ground, the helicopter is going in exactly the same direction as your car, at a speed of two hundred miles per hour. So, if the helicopter is traveling at a speed of two hundred miles per hour, um, the car's speed is--relative to the--the very low flying helicopter, um--so the helicopter's going much faster than the car is because the car is going forty miles per hour. Now, relative to the ground, the helicopter's gonna--OK, ugh, What is your car's speed relative to a very low flying helicopter? Um--well, the car is--going--less, is going slower than the helicopter, um, so, if the car appears to be going forty miles per hour, and the helicopter is going two hundred miles per hour, then the car's speed would be less than two hundred, so, it wouldn't decrease in miles per hour, and it wouldn't stay the same--um, the helicopter--would be traveling--well the car would--hmm--the car--let's see, the helicopter would be traveling at a hundred and sixty, but the car would be traveling at--the car would be traveling at forty miles per hour, because, the helicopter is traveling much quicker. So, um, the speed would be forty miles per hour, um, I don't know what to say, um, I would stay with 40 because, it won't be going, it won't be going--it can't go slower than it already is going. Um, hmm--how confident are you in your answer? I don't know. My answer is just a blind guess.

38 I: And you could you say again how you got it please?

39 AC3: Um, well I didn't--I just assumed that--that the speed would stay the same, um, relative to a low flying helicopter. Um, I don't have any formula or anything that I used on the other ones [emphasis added], but because it can't because the car would not, not go slower than 35 miles per hour, and it wouldn't go quicker than 40 miles per hour, because, because the helicop--hmm--I don't know how to explain it. I'll just go on to the next one.

40 I: OK.

41 AC3: The white truck is traveling toward your position. If the truck's speedometer read forty miles per hour, what is the truck's speed relative to the helicopter? OK, the helicopter is traveling in the same direction as the gray car, um, truck's speedometer reads forty miles per hour. So, um, the truck's speed relative to the helicopter would not be any, um, greater than forty, because it's going in the opposite direction. And, the helicopter is traveling at two hundred miles per hour, in the opposite direction, so--umm, the truck's speed would not be a hundred and sixty miles per hour. Um, because it's going--it's traveling in the opposite direction, so it'd have to be going slower, so I'm gonna guess forty miles per hour again--Um--

42 I: And your confidence on that one?

43 AC3: Um, I'm fairly confident....

45 I: OK, and ah--ah, why aren't you sure?

46 AC3: 'Cause, well, the last one was forty miles per hour, so the last one could be right, yet it could be--so this one could be wrong. Um, that's why I'm not sure. But, um, I think--I'm

more confident because I know that when a truck is going, uh, in the opposite direction than a helicopter, it either stays the same--the speedometer--would--read the same, or, um, it--well, it would appear to be going slower than the helicopter. So, I'm fairly confident.

Summary

As on the pretest, AC3 accurately answered posttest questions 1, 3, and 5 but inaccurately answered questions 13 and 15. On posttest questions 13 and 15, his reasoning appeared to indicate that the speed of the helicopter relative to the ground does not affect the speeds of the vehicles relative to the helicopter. On posttest questions 1 and 3, he did see that the velocity of the boat relative to the ground affects the speed and direction of the puck relative to the observer. However, as shown above, he questioned his answer for posttest question 5, wondering whether 18 was too fast. Though he inaccurately answered posttest questions 7 and 17, there is evidence that his reasoning was close to accurate on both questions. On posttest question 17, he accurately indicated that the speed of the ball (relative to the truck) would be canceled by the speed of the truck (relative to the ground). He indicated however, that the ball would land to the right of point "P" due to the "extra energy" at release, stating, "when the snowball is released, there's um, an initial um, release of energy, there's a higher release of kinetic energy, um, and, that--that would um, that would be the cause of the snowball landing to the right of 'P.'"

It appears from the above protocol that confusion concerning mechanics principles is a component of the sources of his difficulties. On posttest question 9, which he said was easier than question 7 when asked by the interviewer following the posttest, he accurately reasoned that the person on the cruise ship (Joe) would have to move his telescope to the left to keep the barge worker centered. This correct answer contrasts with his pretest response for question 9. On question 7, AC3 answered that the worker's speed relative to the cruise ship was 0. He answered 0 after considering and dismissing 6 and 4 in turn. He may have started to solve a simpler problem due to overload--perhaps evidenced by his mention of the speed of the barge instead of the worker, toward the end of his solution for 7. He stated that the accompanying diagram was helpful in solving question 9, as the worker was to the left of Joe and he could visualize the scene. Question 11 apparently provided no difficulty for AC3 during either the pretest or the posttest. During the questionnaire section he stated that the diagnostic (which had directions) helped with the simulation activities but not vice versa. Additionally, he indicated that the diagrams connected with the diagnostic questions assisted his ability to picture problems. Below, AC3 responds to the question concerning why he thought that question 9 was easier than question 7.

58 AC3: Because, um, um, there's--I think it's--I think it's just because of the picture, it's more, it's really quite visual. Um, the--it's the visual appearance that the barge worker is to the left of Joe, do that, um, Joe would have to move his telescope to the left. Um, and--well that, that--this this is--this vis--this picture works because, um, the tugboat is--the picture

lines--um, is the same as my answer because the tugboat is going in the opposite direction. But if the tugboat was going in the same direction as the ship, the picture would not coin--coincide with my answer. Um, so, number seven, I had trouble because the--it's not--it's not obvious what the barge worker's speed is relative to the cruise ship. Um--

59 I: OK, what--sorry--what, what's not obvious?

60 AC3: The, uh, speed of the barge worker relative to the cruise ship. From the visual diagram.

61 I: OK, so, so what did you feel was the, uh, effect of the diagram?

62 AC3: Um, well, where it--it shows--it shows the direction that the ships are moving assuming that they're not going backwards. But, um, it, it shows the direction of the ships that are moving, and, and it shows exactly where the barge worker is, and where Joe is, so that, so the barge worker, um, appears to be to the left of Joe.

While the protocol data suggests that numeric calculations were used to solve problems 1 and 5 during both the pretest and the posttest, it is striking that during the posttest, the student not only uses an algorithm, but states why he used the algorithm, stating, "When they're going in the same direction, I think you add" (line 21).

AC4 Case Study

In table 5.6 below, the accuracy of AC4's responses to the diagnostic problems is displayed. (1 indicates correct; 0 indicates incorrect)

Table 5.6

AC4 Test Accuracy

Question	1	3	5	7	9	11	13	15	17	Score
Pretest	1	0	1	0	1	1	1	1	0	67%
Posttest	1	1	1	0	1	1	1	1	0	78%

Below, AC4's responses to pretest questions one through six are contrasted with his responses to posttest questions one through six. It appears that AC4 uses an algorithm to assist his numeric solution of posttest problems 3 and 5. The algorithm does not appear to have been articulated during the pretest. There is evidence that an algorithm very similar to, if not identical to the one employed on these posttest questions, was constructed during the treatment (see evidence for construction of this algorithm in chapter VI).

AC4 Pretest

Below, responses to selected pretest questions for AC3's partner, AC4, are presented.

6: AC4: All right. Okay-dokay. In questions one through six, Toni and Joe are playing air hockey in a cruise ship's game room. Relative to an observer standing on the ground, the ship is traveling to the left at ten miles per hour. One, Tony just hit the puck toward Joe at a speed of right miles per hour relative to the air hockey table. At what speed of the puck relative to the observer on the ground? Okay, the ship is going ten miles per hour, the puck is going 8. So, it's going left at ten, so ten minus eight equal two. All right, two. How confident are you in your answer? Fairly confident in my answer.

7: I: Okay, and how'd you get it?

8: AC4: I subtracted the ten miles an hour, the ship going to the left, minus the eight miles per hour, the puck is going towards Joe tot he right. To the right and got two miles per hour. All right, number three, what direction is the puck traveling relative to the observer on the ground.

9: I: Oh, I'm sorry, I didn't catch your confidence on that one.

10: AC4: Oh, my confidence was c, I'm fairly confident in my answer.

11: I: Okay. why not positive?

12: AC4: Well, I'm not sure if there are any other intangibles that might like, affect it....

14: AC4: Okay, number three. What direction is the puck traveling relative to the observer on the ground? And ah, I got "A" to the right, "B" to the left, or "C" neither. I got "A" to the right [as my answer].

15: I: And how'd you get that?

16: AC4: Um, because despite the fact that the ship is moving to the left, the puck is moving slower so it would appear to be, well, hum, actually, yeah I think it's moving tot he right because the ah, puck is moving at a different rate of speed.

17: I: I see.

18: AC4: Um, again I'm fairly confident in my answer.

19: I: And the same reason why your not completely sure?

20: AC4: Well, I'm not sure if it'll actually appear to be moving left because the speed is greater, moving left than it is going to the right, so.

21: AC4: Okay, can you say some more about that?

22: AC4: Well, if the ship is moving ten miles per hour toward the left, and the puck is only moving eight, I think it would look to the observer like it was moving to the right, but it might actually be moving to the left, because it's going a little slower than the left, the ship is moving.

23: I: I see.

24: AC4: Number five. Joe just hit the puck toward Toni at a speed of eight miles per hour, relative to the air hockey table. What is the speed of the puck relative to the observer on the ground? And ah, that would be ten miles per hour for the ship going left and eight miles per hour for the puck going left, so I'd say it looks to the observer that it's going eighteen miles per hour. And number six, how confident am I in my answer. I'd say fairly confident, not sure totally what it would be.

25: I: Okay, and once again, um, how'd you get your answer?

26: AC4: Um, that if the ship is moving ten and the puck is moving eight, add it together it would be 18 miles per hour.

27: I: Okay.

28: AC4: Okay.

29: And why did you add?

30: AC4: What? What did I add?

31: I: Why did you add?

32: AC4: Um, it just seemed like that if the speeds, it just seemed like the natural thing to do, to combine the speeds, and ah, just to combine then so you'd see the full speed of the puck.

<u>AC4 Posttest</u>

AC4 appears to provide a different type of reason for his solutions to posttest problems one through six. In the protocol below, he appears to refer to a general algorithm. There is evidence that this algorithm was developed during the treatment (See chapter VI for a description of this student's interaction with the treatment.)

17 AC4: In questions one through six, Toni and Joe are playing air hockey in a cruise ship's game room. Relative to an observer standing on the ground, the ship is traveling to the left at ten miles per hour. Number one, Toni just hit the puck towards Joe at a speed of eight miles per hour relative to the air hockey table. What is the speed of the puck relative to the observer on the ground? All right, well, Toni just hit it towards Joe, so it's moving eight miles an hour to the right. And the cruise ship is still moving ten miles an hour to the left. <u>So, that is a change in direction, so, I would subtract eight from ten</u>.

[emphasis added] [possible reference to algorithm constructed during treatment]. Ten minus eight equals two, so, to the observer on the ground, it would appear that the puck would be moving two miles an hour. And.

18 I: OK.

19 AC4: Yeah. And I'm sure that this answer is correct.

20 I: Could you say one more time how you got it?

21 AC4: How? Well, because the direction changes; Toni's hitting it towards Joe, which is going right, and then the boat is going to the left, so there's a direction change, so I got that ten minus eight would equal two. Miles per hour.

22 I: And your confidence in that one?

23 AC4: I'm pretty sure.

24 I: OK.

25 AC4: All right. Number three: What direction is the puck traveling relative to the observer on the ground? Well, the puck is moving at eight miles per hour to the right and the ship is moving at ten miles per hour to the left--so, the--the puck would still be appearing to move--to the--to the observer, it would still appear to move to the--left--because the, um, the speed of the ship going left is greater than the speed moving to the right, so--it would look like, to the observer on the ground, it would look like it was moving to the left. And, I'm fairly confident that's right. All right.

26 I: Why not positive?

27 AC4: Um, I'm not really sure because if it's going two miles an hour, is what I got on the first one, it seems like it

should look like it's going somewhere. But, I--just-like--knowing what happens, I don't think--I still--I'm not really sure exactly what would happen but I'm pretty sure that that's what they would look like.

28 I: Can you say some more about that?

29 AC4: Well, uh, since the ship is moving faster, it--I guess it would look to--to the guy looking up that the puck would still be moving closer to the--to the left side of the page than to the right side. So, it would appear to be moving, ah, left. All right, umm. OK, number five: Joe just hit, hit the puck towards Toni, at a speed of eight miles an hour relative to the air hockey table. What is the speed of the puck relative to the observer on the ground? And, since there's no change in direction on this, I would say that you would add the eight and the ten together this time, and--that would be a total of eighteen miles per hour [emphasis added] [possible reference to general algorithm constructed during the treatment], which is "D." And that's because, um, both things are going in the same direction as they were--as they are--they're both going towards the right. No. Both going towards the left. So that's why it would look, ah, they would both be going--so you'd add them together. And I'm sure that this is right.

In posttest question 3, AC4 indicates that, relative to the observer, the puck would travel to the left. When he answered this question during the pretest, he answered that the puck would travel to the right. Though the difference in reasoning is not tremendous, it is indicative of a change in viewpoint. He indicates that using the computer simulation allowed him to construct a rule for determining the interrelationship of direction with relative speed.

Another interesting portion of his posttest is contained in his answer to posttest question 3 in which it appears that though he answered correctly, he apparently was fighting an epistemological commitment (for a similar concept, see Brown, 1995) that, since the puck had a speed, you would have to see the effect of that speed.

Summary

The interviewed DN students performed better on the relative motion posttest than on the identical pretest ($p<.01$). As the students engaged in the numeric (DN) treatment condition, it is not surprising that the biggest difference between pretest average and posttest average were seen on numeric questions 13 and 15, with three of eight subjects improving their accuracy on both questions on the posttest. Many interviewed DN students displayed evidence of algorithm use while solving posttest problems. There is evidence that many students referred to algorithms which were developed during the DN treatment (e.g., subjects AF1, AF2 and AC4).

Concerning individual students, AF1 appears to have used an accurate algorithm when solving posttest problems 13 and 15; in contrast to the faulty algorithm applied to pretest problems 13 and 15. This advance may have been caused by interaction with the computer simulation activities, as a similar algorithm to the one applied to posttest questions 13 and 15 was expressed during the treatment (see chapter VI). AF1 may have experienced conceptual change; during the posttest, unlike the pretest, the directional solution for question 9 was consistent with the numeric solution for question 7. This result supports the hypothesis that during the posttest, numeric and visual models constructed by AF1 for questions 7 and 9 were compatible. During the posttest, subject AC3, on the other hand, gave inconsistent responses for questions 7 and 9. Like other students, there is evidence that student AF2 successfully used algorithms to calculate relative speeds. He also appears to have developed a (faulty) algorithm for determining the direction of travel of objects in relative motion.

It can be reasoned that the performance gains were the result of interaction with the DN treatment. Additionally, it appears that the gains are not limited to one type of student (i.e. high achieving or low achieving on the pretest), as all but one student scored higher on the posttest than on the pretest. However, it is not clear whether the improvement in test performance may be attributed to deep understanding or to a better ability to manipulate the numbers on numeric problems such as problems 13 and 15. It is also illuminating to see how interaction with the numeric treatment apparently led to the faulty visual algorithm used by AF2 during his solution to posttest problem five.

CHAPTER VI

TREATMENT INTERVIEW DATA

Introduction

In this chapter, case studies of students interacting with the computer simulation activities are presented. These case studies, taken from interviewed students, are presented to document learning approaches used by students when interacting with the computer simulation activities. Particularly striking in the data are algorithm indicators and visualization indicators. Due to the apparent ease of predictions for students in the CV condition (see statistics in chapter III), more space is dedicated to students' interactions with the DN condition. These case studies will be used to develop a means for analysis of the occurrence of algorithm use and visualization use. They can also provide evidence which motivates hypotheses concerning how interaction with the two conditions (CV and DN) was different.

Relative Motion Problem Solving Approaches

In figure 6.1 below are hypothesized methods for approaching relative motion problems, including the predictions performed during the simulation activities. Different shades of meaning can be applied to the term algorithm, moving from mechanical to insightful, where a formula could indicate an elegant understanding of a non-visual system, for instance (see Feynmann, 1960 as referred to by Tweeney, 1995). Often, in the following discussion, mechanistic algorithm use is contrasted with intentional visualization involving deeper cognitive effort.

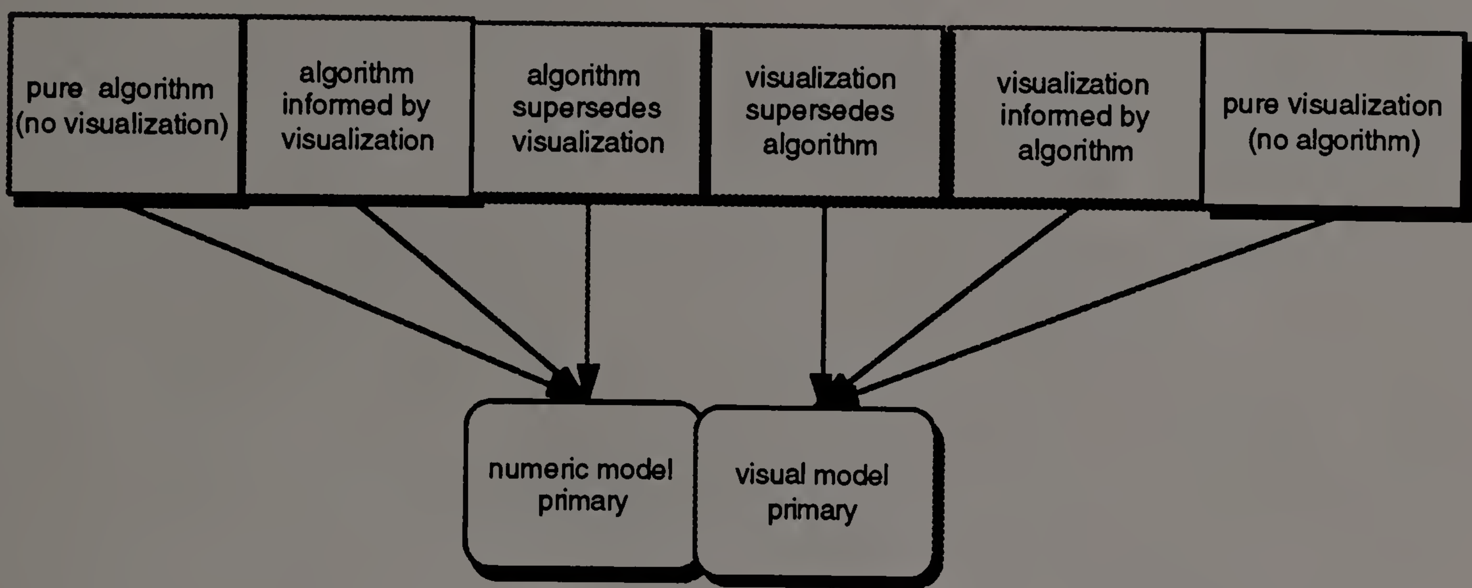


Figure 6.1

Hypothesized methods for approaching relative motion problems

I hypothesize the following indicators for algorithm use, where higher numbered indicators are more reliable and would be more able to stand alone in the absence of other evidence:

1. statement of the algorithm used
2. statement of applicability of algorithm (e.g., when the two things are approaching each other you add.)
3. mention of mathematical procedure (e.g., addition or subtraction)
4. reference to using same method as previous problem solved via algorithm
5. pattern recognition applied incorrectly
6. non-reflective reference to previous problem (in combination with other indicators, only)
7. lack of visualization indicators

8. quick response (may be indicator of lack of reflection)

9. low confidence in prediction

Finke (1989) defined mental imagery as:

> the mental invention or recreation of an experience that in at least some respects resembles the experience of actually perceiving an object or an event, either in conjunction with, or in the absence of, direct sensory stimulation. (p. 2)

Clement (1994) posited indicators for determining the occurrence of imagistic simulation. Indicators include: "personal action projections (describing a system action in terms of a human action), kinesthetic imagery reports, ... depictive hand motions," use of "imagery enhancement techniques" (such as "painting" dots on an imagined spring when determining how the spring would deflect), and "announcement of the intention to form an image of the situation." Concerning specific subjects he stated,

> The presence of dynamic imagery reports, hand motions, imagery enhancement techniques, and the effort put into imagistic simulations all support the view that simulations in this case are very different from descriptive, language-like representations. These observations and the subjects' reports of experiencing the effects of actions occurring over time provide a real motive for using the term "simulation." They suggest that the subjects are somehow mentally simulating some aspects of the rich flow of perceptions and/or motor actions over time that would exist if they were actually viewing and/or causing such events. (p. 154)

In analyzing students' protocols, I looked for instances of the indicators described above to provide evidence for students' visualizations.

Below, I present case study protocol from selected interactions with the DN and CV conditions. In general, CV students appear to have visualized often during the treatment. Among the DN students, evidence indicates that a variety of strategies were employed, including mechanical use of algorithms as well as visualization.

Treatment Case Studies

AF1 & AF2 DN Treatment

As an example of a pair of DN students' apparent ability to construct numeric and visual models, consider the interaction between subjects AF1 and AF2 during simulation activity 2. During this activity, as shown by the transcript, AF2 is dominating. Below, I present AF2's indicators of both visualization and algorithm use.

Overall, subject AF2 appeared able to use visualization to assist solution of relative motion problems. Indicators of visualization occur in his pretest and posttest protocols and during his interaction with collaborative simulation activities. He appeared to use a number of strategies for solving relative motion problems. Evidence for problem solving strategies are evident in his interaction with his partner during simulation 2. Simulation 2 is particularly interesting as many students in the DN condition had difficulty with simulation 2 predictions. Specifically, many students inaccurately predicted the speed of the striped rectangle (called a striped car in the CV condition) relative to the white triangle (called an airplane in the CV condition).

82 AF1: X is, going to be going 60 to the right.

83 AF2: Yep, no, ah, sixty ah--

84 AF1: To the left? I don't know.

85 AF2: Ah, it's going to be going sixty, but ah, it's going to go the opposite way I th--, wait. Now, they were both going in the same direction when ah, the x was a reference. Now that ah, now that that's the reference, sixty's zero becomes the going speed, so it would actually yeah, be sixty to the left, because the pennant is going faster, and that's what you're focusing on, so it would appear as if the x is going the other way, it's going slower [possible combination of algorithm use and visualization use--it is not clear which is dominant, if either].

86 AF1: Yeah, I got ya.

87 AF2: So it'd be--

88 AF1/AF2: Sixty to the left. [indication that the student is not operating simply in numeric mode]

89 AF2: So, 60, 180. [indicates ability to use different representations--one more visual (to the left), the other more numeric (60, 180).]

90 AF1/AF2: Pennant at zero, zero. [indication of understanding that reference frame's speed is 0]

91 AF2: And the box would be--

92 AF1: It's going to be--

93 AF2: 35 to the left for the same reason as x [apparently, algorithm use simplifies process--no need to visualize scenario due to confidence in previous reasoning].

94 AF1: Yep, yep, yep.

95 AF2: And the stripped box is going 25....

96 AF1: To the left.

97 AF2: ... to the left, that's the opposite direction to the x. So, the pennant is going this way--

98 AF1: So isn't it going to go 35 to the right? Yeah.

99 AF2: Why's that?

100 AF1: Well, I mean 25, th, the black square is going 25 to the right.

101 AF2: Oh, yeah, they're both opposites, so, 35 to the right. Okay, so, the x is going--in--when the, when x was a reference, the pennant went 60 faster. When x was a reference, the pennant went sixty faster.

102 AF1: To the right.

103 AF2: In the same direction. So, when pennant, when the pennant is the reference, the x will be going the same speed in the other direction.

104 AF1: Or, the pennant will be outdistancing the x by sixty.

105 AF2: And ah, the pennant is zero, we know the pennant is going right, because of the ah, x.

106 AF1: So, it doesn't have any speed 'cause it's the reference.

107 AF2: Yeah. And the black box we know is going 35 in the same direction, in, in the opposite direction 'cause when the x was a reference, it was going 35 slower than the pennant.

108 AF1: Yep. (scribbling) Okay, and then for the next one it's the same thing, only it's um, it's the opposite direction.

109 AF2: Yep, yeah it would, it would appear to be going thirty. Okay.

110 AF1: All righty.

111 AF2: Okay, we're sure again.

In the following protocol, AF1 and AF2 check the accuracy of their predictions and realize that their prediction for the striped rectangle was incorrect. (Six of eight interviewed DN students' predictions for the striped rectangle were incorrect; 39% of the honors physics students' (in the DNhon class) predictions for the striped rectangle were incorrect.)

115 AF2: So the white triangle's zero, zero right about that.... 35, 180 for the black triangle, which is correct.

116 AF1: Oh yeah!

117 AF2: ... 85, 180. We got that one wrong.

118 AF1: How did we do that?

119 AF2: 85, 180, well we got the direction, um, no we got the wrong direction.

120 AF1: Wrong direction.

121 AF2: Wrong direction, wrong everything. Okay, let's look at this again. When the x was a reference, it was going, when the x was a reference it was going 25, 180. So, it's going the opposite direction as both the x and the pennant. Right, and it's going, it was 25 faster than the x.

122 AF1: That's moving this way.

123 AF2: So, it's going this way at 25, when this is zero. And this is going this way at 60. No, not that, this. 25, and this one was going this way, 25. And when this is the, when the white pennant is the reference, it's going right.

124 AF1: That thing was going 60, so maybe that's, let's see it's, it's actually--

125 AF2: It's going, why are we, how could he get 85?

126 AF1: Well, 85 is, is 60 and 25.

127 AF2: No that's, yeah, yeah 85 and 60. So, when the white pennant is going right at sixty, that is the reference, then everything is, everything is, you add sixty to, ev, everything. Sixty right, and if something is going left, and you add sixty right, I think it's the same as just saying 85, 180, and leaving it the same. That's the only way I can think of. And I guess if you add sixty right to 25, it's like, it's like subtracting, so you get negative 35 right, which is also 35 left. And if you add sixty right to this, you get negative sixty right, which is also sixty left. So if we just did that--

128 AF1: Yeah, but what's 35 left? That's not right, is it? Oh, but it is. Yeah, that's right.

129 AF2: So, you just add the like zeros and negative, so that's why it would be 85, 180. So, we'll say, yes, yes, yes, no, because um--

130 AF1: 'Cause we didn't add it through.

131 AF2: 'Cause we didn't ah--

132 AF1: I mean subtract, I mean add.

133 AF2: Did not take into account-- (scribbling)

134 AF1: Didn't take into account the--

135 AF2: The sixt, the sixty right, instead of um, what we did was, we ah, we just assumed it was the opposite as the black one, which it's not. We were supposed to add the sixty right to the 25 left which would have gotten 85 right, or 85 left.

136 AF1: Uh, hum. Right.

137 AF2: Okay.

138 I: Okay.

139 AF1: All righty.

In the above, though the students use algorithms, many different forms of processing appear evident, from visualization aiding algorithm use to algorithms used without reflection, to algorithm modification based on anomalous data. Indeed, it appears that the effect of anomalous data is significant (see data starting with line 121).

AFl and AF2 displayed concern that the direction of travel associated with zero speed was not as they had predicted, like subjects AA1 and AA2, who also received the DN treatment. Neither pair of students realized that no direction needs to be associated with a speed of zero. This difficulty may be a symptom of an endemic problem for students' interaction with software--namely the computer is not critically examined for trustworthiness--the computer is considered to always be accurate. Or, more accurately, a student may uncritically believe his or her interpretation of the meaning of computer output (See Monaghan &

Clement, 1994b.) However, the fact that classroom tests have shown gains by students in the DN condition may imply that students are able to accurately form numeric and visual models following interaction with the computer simulation activities.

AC3 & AC4 DN Treatment

There is evidence that the students applied algorithms in solving problems. This evidence is provided by the student's reference back to a previous similar problem and stating of numeric relations like "I think it's probably umm--60 minus 25: [speed] 35, [direction] 0 ."

It appears that the development and implementation of an algorithm can be traced starting with initial development during the prediction phase of simulation 2 (see lines 172 to 235 of transcript), modification based on anomalous information (see Chinn & Brewer, 1993 for a discussion of students' responses to anomalies) as evidenced in the explanation phase of simulation 2 (see lines 257 to 272), application of the modified algorithm to simulation 3 predictions, and subsequent application to simulation 4 activities. There may be evidence that at times during the activities the word direction did not engender a visual representation, but was merely a variable name. Protocol from their interaction with simulation 2 follows.

172 AC4: The white triangle will be [speed] 0, [direction] 0 because it's the point of reference.

173 AC3: Yeah that's right. Reason for prediction--point of reference. Okay--umm confidence--?

174 AC4: Sure.

175 AC3: Sure. Okay--umm now what are--okay so the X is going [speed] 0, [direction] 0 in comparison to the triangle which is going 60, 0.

176 AC4: All right Umm hold on. I'll bet that it [the X] will be going [speed] 60, [direction] 180 'cause on the last one that's what happened.

177 AC3: Yeah, yeah you're right.

178 I: Which one is that?

179 AC4: The X, we think it would be going 60, 180

180 AC3: Yeah because--

181 AC4: Before it was like that on the other one. So umm--changed direction.

182 AC3: X changed direction and appears to go faster than white triangle.

183 AC4: All right and then--

184 I: You said like before?...

188 AC4: We changed the point of reference the one were the point of reference--changed 180 and--and there are--their speed was that of the new point of references.

189 I: Which one are you talking about?

190 AC4: Well on the old one the gray circle became the point of reference and originally it was 4, 0 and so that changed to be a 4, 180 so that's how we got the new one. [analogous reasoning to previous case]

191 I: Okay thanks.

192 AC4: All right.

193 AC3: The confidence ahh?

194 AC4: I'm sure.

195 AC3: All right.

196 AC4: Umm--lets see--the black rectangle I would say--

197 AC3: Lets see, it's going 25, 0--for in comparison to X so it's going faster than the X. Umm--

198 (pause)

199 AC4: Maybe 35--subtracting from 60 [emphasis added] 60 minus 25 [emphasis added]

200 AC3: Yeah because.... yeah it's like the X it would be going at a different direction, I guess.

201 AC4: The 35 is right?--for the umm black rectangle.

202 AC3: Well the reference point is--is 0, 0.

203 AC4: But it was 60, 0

204 AC3: Yeah it was going faster than--yeah it would have to be--'cause the X is going even slower than the black rectangle in comparison to the point of reference so--yeah they both are going slow in comparison to the white triangle [possible combination of methods; this student appears to employ visualization as well as numeric methods].

205 AC4: Yeah so 180 is the result of the change in direction?

206 AC3: Yeah.

207 AC4: And then it would be 60 of the white triangle minus 25 for the black triangle when you first had this test so that would be 35 total--

210 AC4: I'm pretty confident; I'm not sure though.

211 AC3: 60 minus 25 equals 35?

212 AC4: Mmm hmm, I'm pretty sure.

213 I: Which one was that?

214 AC4: This is the black rectangle.

215 I: Okay.

216 AC3: Fairly confident or sure?

217 AC4: Umm, I don't know for sure.

218 AC3: Yeah

219 AC4: It's a little sketchy.

220 AC3: Yeah it's a little difficult to discern.

221 AC4: Okay, and then finally, the striped rectangle would probably be--

222 AC3: You see, it's changing direction--so do you think it's going the same direction as the white triangle now?

223 AC4: I think it's going zero. Yeah I think it's probably umm 60 minus 25 [thus, speed = 35]

224 AC3: Yeah I think so.

225 AC4: That's basically for the same reason as the black rectangle--because it changed direction.

226 AC3: Right.

227 AC4: From [direction] 180 to 0--and then you subtract the 60 [minus] 25 thing. (pause) All right. So, I guess we are about finished. Oh, we have to do the confidence level here--

231 ... You think you're sure?

232 AC4: I'm pretty sure.

233 AC3: All right.

234 AC4: I'm sure.

The inconsistency of predictions for the grey triangle (new frame of reference) and the small black triangle (whose speed equaled that of the grey triangle) provides evidence that different rules were applied to the reference frame as for other objects. The rule applied to their prediction for the objects including the small black triangle consisted of 2 parts:

1. Check if direction (as measured from the original frame) is 180; if this direction is 180, take the object's speed relative to the original frame (in this case 2), and add it to the new frame's speed relative to the original frame of reference (again it was 2) to get the speed; the direction will be 180
2. If the direction (as measured from the original frame) is 0, then take the object's speed relative to the original frame and subtract the speed of the new frame of reference relative to the original frame of reference; the direction will be changed to 180.

This is contrasted with the more effortful and thoughtful application of heuristics by AA1 and AA2. There appears to have been a switch in approach used. Possible visualization indicators by subject AC3 became less frequent to non-existent following simulation 1. Below, there is evidence that the students modified their algorithm following unexpected computer output.

257 AC4: Well, all of ours matched except for the striped triangle and ahh I would guess that's probably cause ahh you add the 25 when you switch the direction rather than subtract it [indication that algorithm was incorrect].

258 AC3: Right so yep. So yeah, add 25 to what?

259 AC4: To the 60.

260 AC3: Yep. Add 25 rather than subtract. Is the direction the same?

261 AC4: Yeah we went from 180 to zero rather than from zero to 180 so that's probably why--we probably fouled up.

262 AC3: Direction--

263 AC3: So is the direction right?

264 AC4: In the direction it was. Hold on.

265 AC3: Yeah the direc--whoa, direction is wrong!

266 AC4: Yeah we got the direction wrong.

267 AC3: That accounted for--for adding it instead of subtracting--

268 AC4: Subtracting

269 AC3: Subtracting instead of adding, sorry.

270 AC4: All right (pause).

271 AC3: Okay.

272 I: And what was the explanation then?

273 AC4: Umm, that we decided to change it from [direction] 180 to [direction] 0 and it should have stayed 180 and instead we subtracted 25 from 60 rather than adding. [apparent statement of algorithmic thinking. AC4 appeared to be solely in algorithm mode ('let's get it finished' mode).]

There are several instances of algorithm use by the DN students. One particularly telling vignette is as follows, which occurs during Galilean Relativity 3 simulation activity.

295 AC4: ... The black circle ... would be 3, 180. 'Cause ... it wouldn't switch directions; you'd add.

296 AC3: From 180--and the gray circle is going to--why isn't it switching direction?

297 AC4: Umm, I'm just guessing cause last time when we had [polar direction] 180 it didn't switch direction it stayed ahh (pause) stayed 180 and you added on to get 85 rather than--oh--no wait--yeah--stayed 180 rather than switching to zero and you added on to the 60 [reference to previous simulation anomalous case--striped rectangle] or whatever [emphasis added].

298 AC3: All right. That's 3, 180.

299 I: That's for which one?

300 AC4: For black circle

In the above protocol, subject AC4 indicates that his prediction is just a guess (see line 297). He apparently indicates that he derived his answer through pattern recognition at the surface level, stating that any object whose direction was 180 in the original frame of reference, will have a direction of 180 from the new frame of reference (line 297).

It is striking to note that, while AA1 & AA2 and AF1 & AF2 used the words "left" and "right" in speaking about the direction of travel of objects, subjects AC3 & AC4 and AB1 & AB2, predominantly used 180 and 0 and did not appear to employ a mapping of the numbers to direction as a major part of their strategies. AC3 appears to show signs of this form of mapping during simulation 1; there is less compelling evidence that AC4 had made a mapping (he responded "yes" when AC3 asked if 180 meant an object was traveling to the right) during simulation 1. However, the lack of reference to direction strongly suggests that the students did not employ a visual model when making predictions. This argument is supported by their statement of the algorithms used, the applicability of the algorithms, and the use of the algorithm with little effort (based on apparently rapid responses--particularly by AC4).

<u>AA1 & AA2 DN Treatment</u>

AA2 was dominant in the interactions. She showed signs of visualization during each simulation activity. However, as evidenced during her prediction for the black circle of simulation 1, she apparently used an algorithm to facilitate easier solution of this component of the exercise. It should be noted, however, that unlike subjects AC3 & AC4, this pair referred to a direction of 180 as "left" and a direction of 0 as "right," indicating that visualization may have been an integral part of their reasoning. Indeed, there are indicators of visualization throughout both of these students' treatment protocol.

83 AA1: Yeah. (pause) Okay. The black circle was going to the right six before.

84 AA2: Yep. I think it would still be going to the right.

85 AA1: Are you sure?

86 AA2: No. (laughs)

87 AA1: 'Cause the frame of reference before, I think it would be opposite. I think it would be going six to the left because, I'm not sure how to explain it, but, before the frame of reference, in the new frame of reference, was going to the right four, well. I'm not sure how to explain it, I just think that's

what it is (laughs). 'Cause like, just switching. ["switching" appears to be the algorithm employed].

88 AA2: Um, no, okay. If yeah, if you think about the direction the frame of reference was going before.

89 AA1: 'Cause the, the direction. Okay, here's, here's the idea. The, it was going the same direction as, oh, the same direction as every else, 'cause everything was going to the right. See, this is probably going to the left. 'Cause everything-

90 AA2: Everything is going to the same direction as before.

91 AA1: Yeah. But then again, maybe this is still going to the right. Um, it's going, but, and if it is going to the left, then this would be going to the left too. But, the same, probably?

92 AA2: Probably.

93 AA1: Because everything else is sort of the same, except switched, when.

94 AA2: Yeah.

95 AA1: A different reference point. So, it should still be going-- Oh I get it. When something is going the speed of zero, it's actually moving, but not in relation to itself [suggests a primitive understanding of frame of reference concept; the implied preferred reference frame is ground], like, this was moving the same speed as this, in the same direction probably.

96 AA2: Oh, okay.

97 AA1: ... 'Cause it's half in the other direction if it's not moving.

98 AA2: But if you're okay (laughs).

99 AA1: I think that must be what it is.

100 I: Okay, and did you discuss your confidences?

101 AA2: Uh, on the gray triangle, black circle.

102 AA1: For gray triangle, um fairly confident in how it's like--

103 AA2: It makes sense.

104 AA1: But I'm not very confident of the black circle, cause that one didn't quite make sense [possible indicator of lack of understanding of algorithm used]. Does that make, does that sound right to you?

105 AA2: Um, yeah, I agree.

Below, she realizes that the algorithm was incorrect.

121 AA1: The only one that didn't match was the, the black circle.

122 AA2: The, the, well we said the gray circle was going to the, to the left when it was to the right.

123 AA1: Oh, that's right, yeah, originally we said that it was, and then we said that it wasn't.

124 AA2: Okay, it was going two.

125 AA1: What?

126 AA1: I think that, hum. I have no idea why it turned out that way (laughs). Just like I had no idea how to figure it out.

127 AA1: I think maybe it didn't work because, what we did didn't work because just switching the direction and keeping the same speed doesn't work [emphasis added] [indication that algorithm was not effective].

128 AA2: We didn't take into account the new circumstances.

129 AA1: Right. Right. But, I wasn't sure exactly how to do that. But it made sense with these two triangles, because they were going zero, so that one was easy to switch around, or this one 'cause it was going zero before. So, because, okay--

130 AA2: Sort of like because they use the same like, the same, what do you call it, like, um, it's like we used the same things that like if it happened, we used the same, like if it happened with this we thought automatically should happen with this [emphasis added] [analogical reasoning] [possible algorithm indicator].

131 AA1: Uh-hum. That, that could be a different speed relative, speed.

132 AA2: Yeah. (scribbling) Okay.

133 AA1: So, with the circle, I'm not, we have the speed but weren't sure of the direction of it.

134 AA2: Yeah.... But we did that and then we changed it afterwards. Um--

135 AA1: I'm not sure on that one either, I'm not sure how to tell what direction something is going. [emphasis added] [may indicate that students did not visualize the scenario.]

136 AA2: Yeah.

137 AA1: If it's not going at the speed--

138 AA2: It's confusing.

139 AA1: Um-hum.

In the second simulation, there is evidence for use of a strategy in which algorithms appear to be informed by visualization, as shown in the following. Below, AA1 and AA2 explain the reasons for their simulation 2 predictions.

192 AA1: Okay. The reason for the "X" was that, um

193 AA2: That's what we did before, right? Switching the, switching to the old, to what the old frame of, the new, okay switching to what?

194 AA1: Because, because the one was--(scribbling) and so the frame of reference is not moving, relative to itself. It's not--(scribbling) Okay, and this one is a little more difficult to explain. That--

195 AA2: Because its speed is--

196 AA1: Using it's speed from before, using its old speed, using--

197 AA2: The triangles' old speed. Okay. Okay.

198 AA1: So if that worked with that one, the same thing should work on the stripy one, which is going towards the triangle in the old, in the old, in the old-- Toward the triangle at 25 also, so it should also be going 35 Oh wait, no it was going, you know what? The left triangle is moving away, 'cause it was going to the right. [visualization indicators] Black circle.

199 AA2: Square, it was going to the right?

200 AA1: Yeah, in the last experiment. So this should be true of the, can we just switch this shapes?

201 AA2: Uh-huh.

202 AA1: Okay. So this one's going to be 25 in the other direction, so adding it together should make sense [emphasis added] [visualization may have informed algorithm].

203 AA2: Yeah. Maybe so.

204 AA1: 'Cause going 25. Wait a second.

205 AA2: It's still, no that triangle is still going to go--

206 AA1: Triangle is going 60, in the same direction as 25

207 AA2: So, actually it will still do what you were talking about before and look like it's going the other way.

208 AA1: Oh right, 'cause this is goin' to the right, but it's gonna go faster, so it's gonna, so it actually looks like it's going in that direction, okay, so never mind. (laughs along w/ AA2) I forgot my reasons, okay, this one is moving the same direction, this one's moving the opposite direction, so it's going to pass, so my adding does make sense [emphasis added] [apparent case of visualization informing algorithm].

Additional evidence for visualization as well as algorithm use occurs during the simulation 3 activities. Protocol follows.

257 I: Okay, so if you could please ah, make a prediction, and indicate the reason for you prediction and the confidence in your prediction. Feel free to look back at your notes, and please discuss those with your partner.

258 AA1: Okay, um. So, what did we do yesterday? Switching the--

259 AA2: Right, since--so, the switching part would be, is relative to this, this would be, two away.

260 AA1: Because the um, black triangle is um, like switching with the grey quadrilateral (short pause while writing).

261 AA2: Okay, the next one, and the gray quadrilateral is the zeros.

262 AA1: Yeah.

263 AA2: And I'm not sure what direction.

264 AA1: I would say zero because, didn't that happen yesterday where everything else switched direction except for the frame of reference? [emphasis added]

265 AA2: Um--

266 AA1: I could be remembering something different.

267 AA2: Yeah, I was just about to say--if, let's go back to this one. This one's going right. Okay. Okay, now we're doing them relative to the gray quadrilateral?

268 AA1: Yeah.

269 AA2: So it's going this way at a speed of two, and the circle's going at a speed of one.

270 AA1: Um-hum.

271 AA2: This one's going faster, so it's moving away faster.

272 AA1: The, this one, oh, yeah.

273 AA2: They're getting further apart. So it's like this one relative to this one is going to the left. So, we know that one's going to the left. And a speed of--

274 AA1: Yeah, two.

275 AA2: Two. But wait a second, I don't know if we're adding, because, would it be, because this one going away.

276 AA1: 'Cause this one's going away at two, and this one's going away at--

277 AA2: No.

278 AA1: No, I think you'd be subtracting.

279 AA2: No, 'cause it going two in this direction as well, so it's only one minute's moving.

280 AA1: Yeah, um.

281 AA2: And that other one, that other circle. That one would be three because it's moving in the other direction.

282 AA1: Yeah, it's moving the other--

283 AA2: And it would be--

284 AA1: It would be going to the left.

285 AA2: Uh-huh.

286 AA1: So the reason for the black circle is--

287 AA1: It's going away from the, away from the grey quadrilateral (pause as she writes).

288 AA2: It 's like they're combined.

289 AA1: Um, the speeds are three.

290 AA2: And the other one is--

291 AA1: The grey quadrilateral's moving faster.

After accurately predicting the speeds and directions of the objects for simulations 2 and 3, they also accurately predicted the speeds and directions for all of the simulation 4 objects. However, it appears that despite their correct predictions they have difficulty with understanding direction data provided when the speed of an object is 0 This difficulty may indicate difficulty with the concept of 0 speed, difficulty caused by the paradox of having a direction associated with 0 speed, or a difficulty with understanding that 0 speed means that the object is motionless and thus cannot have a direction. In this case, the interface, which provides a direction with a reading of 0 speed, appears to contribute to students' difficulties. Protocol from the explain phase of simulation 4 activity follows.

401 I: Okay and the last page is did your predictions match your observations?

402 AA1: Almost.

403 I: Okay, if it didn't please put down a reason for why you think it happened the way it did. And please discuss it with your partner.

404 AA1: White triangle--

405 AA2: There was one that didn't.

406 AA1: Oh, the black triangle?

407 AA2: <u>Yeah the direction was messed up. I don't understand that at all</u>. [emphasis added]

408 AA1: I don't either.

409 AA2: The direction, well, if it's not going, what I don't understand is if it's not going anywhere relative to the whatever the reference point is, then how can you tell which direction it is? [This confusion is possibly due to the computer interface; the students' understanding appears insufficient to overcome apparently non-intuitive computer output.]

410 AA1: Well, it is going, it's going 180, and we said the new frame of reference was go, see we said the triangle's going

zero, and before so, it would have probably gone the same. Does that make sense to you? Did I say that right?

411 AA2: I think, I sort of understand, but I don't know why--

412 AA1: Like they were both going, but when we changed the frame of reference it was going zero, so it would change to zero too, but that's just like thrown out.

413 AA2: Maybe, since, maybe since you know maybe since when the fr, the whatever it is reference, it's going zero, zero to itself anything that would be going the same as it would be going zero, zero.

414 AA1: Yeah.

415 AA2; So, it's the only reasoning I could possibly think up.

416 AA1: It's all we came up with? Yeah, anything (brief pause).

417 AA2: Okay.

418 I: I'm sorry, could you just say aloud your reasons?

419 AA2: For this?

420 I: Yes, please.

421 AA2: Well, the only thing I could think of was that, if something is not going, if something is going zero relative to the reference point or, frame of reference, I forget what it's called, then it's not going anywhere relative to it, but it's also going in the same direction as it, so since it's going zero, the direction's zero, then the black tria, triangle should be going--

422 AA1: Zero too.

423 I: I didn't, I didn't hear the last sentence, what, and what?

424 AA2: Since the, this is going this is going zero, zero then this should be going direction zero too.

AH1 & AH2 CV Treatment

Like all CV students, AH1 and AH2 consistently displayed evidence for visualization during the treatment. For example, below AH1 and AH2 discuss their predictions for simulation 1.

30 I: OK, so now, we've, we've changed the frame of reference and it's the, ugh gray circle or what we're calling the bike frame. What I'd like you to do after you fill in the frame of reference is, make a prediction about what direction each object will travel on the computer screen, now that we're in the bike, or gray circle frame. And what I'd like to say is that it's still the same event as last time, OK? So if you could please, ugh, make a prediction, ugh, indicate a reason for your prediction, and, and state confidence in your prediction, and on all of those, could you please discuss it with your partner?

31 AH1: OK, so gray circle (pause) OK. Should we talk about it before we fill it in?

32 I: Yes, if, if you would please.

33 AH1: Um, OK, so the gray circle's right here, and it's, it starts out to the right of the pyramid, so when it's moving--

34 AH2: Um, hmm.

35 AH1: Basically I figure if, since the frame of reference, it's going to um--it--everything else is going to be moving, by its frame of reference--

36 AH2: Um, hmm.

37 AH1: So I would think that this pyramid's going to go left, and this one's going to come at it, so it would be going left.

38 AH2: Umm Hmm

39 AH1: Umm, and this one's, this one's [black circle] going to be closing this gap [between the black circle and the grey circle] [emphasis added].

40 AH2: Right, yeah.

41 AH1: So, I'd say it's going to the right.

42 AH2: Yep, that's, that's how I see it.

43 AH1: OK.

44 AH2: Exactly.

45 AH1: So, both the pyramids are gonna, are going to travel left (pause) and the, the red [black] dot is going to go to the right, cause it's going to close the re--the gap [see figure 6.2 for AH1's hand motions]. And then I would say the gray, the person on the bike, the gray dot, to itself would be going still.

46 AH2: Of course.

Figure 6.2

AH1's hand motions as he states: "It's going to close ... the gap."

During AH1 and AH2's interaction with the CV simulation activities, numerous visualization indicators were present. While making predictions, AH1 pointed to objects on the computer screen and moved his hand (sometimes while holding a pen) to the right or to the left in combination with statements concerning the direction of travel of objects (see figure 6.2). Additionally, as seen in line 39 and elsewhere, spatial inferences concerning the travel of the objects were drawn.

<u>AC1 & AC2 CV Treatment</u>

During simulation activity 1, AC1 expresses surprise with apparently unexpected output of the computer simulation . AC2 appears to assist AC1 in understanding the simulation output, as indicated in the following protocol:

AC1: Why isn't the bike [frame of reference] moving?

AC2: If we're, I would think that if we were in like the focus of, we're on the bike, um, and you're looking down [points down with pen in right hand], we're going [moves right hand to the right] along with the bike so it doesn't look like it's [the bike] going.

AC1: Oh, OK. Right so then we pass pyramids, and then the dog passes us [moves right hand back and forth].

AC2: The dog passes us.

During the above interaction, both students appear to employ dynamic mental imagery (see Clement, 1994; Finke, 1989), evidenced by hand motions, reports of self-projection, and the report of multiple states of the scenario. I hypothesize that such mental imagery during the treatment may assist students in visualization of relative motion problems when the computer simulation is absent (see Monaghan & Clement, 1994a; 1994b for similar results).

Summary

In general, data supports the position that the CV condition promoted visualization among students during the treatment. Additionally, there is evidence that following interaction with the CV treatment, selected students were able to better visualize posttest problems. If the trends shown by the selected students were to hold true for the general population of high school science students, this type of animation treatment condition could assist students in visualizing problems and may assist development of general ability to mentally simulate dynamic events. Additionally, the CV condition appears to be able to focus student attention on visual aspects of the problems; this may predispose students to a more visual approach than numeric approach to problem solving. This is contrasted with the numeric focus of many students involved in the DN condition. The hypotheses that the CV condition both assisted visualization and could predispose students to use visualization appears consistent with the data.

Within the DN condition, there was more apparent variety in the strategies employed. Whereas students in the CV condition showed evidence for visualization during the treatment and no other apparent interactions, students in the DN condition showed evidence for visualization and for mechanical algorithm use, and combinations of both strategies. Even when students appeared capable of visualizing events, there is evidence that they often employed mechanical algorithms. The analysis that algorithms were used by such students to simplify the problems is consistent with much protocol data.

However, the contextualized/decontextualized variable may be another salient factor in explaining the apparent surface level processing of many DN students. Even when there is evidence for DN students visualizing scenarios (see, for instance, AF1 and AF2), it may have been difficult to attribute a real world scene to the simulation, as the icons were rather abstract. (For instance, AF1 and AF2 called the white triangle of simulation 2 a pennant; for the CV students it was an airplane.) This may have contributed to a student perception that the goal of the exercise was to successfully manipulate the numbers (for a similar finding, see Hammer, 1994). However, students in both the DN condition and the CV condition were able to transfer lessons learned during the treatments to their solution of posttest problems. There is evidence that algorithms used and modified during the DN treatment appear to have been used by students during the posttest.

Concerning the decontextualized/contextualized variable, it appears, based on posttest protocol evidence from AC1 and AE2, that the CV condition was weakly enough constrained that students could use memory of their experience with the treatment to assist visualization and solution of posttest problems. The icons had been designed to be "iconic" (see White, 1993), i.e., suggestive of a context, but only in the presence of the "cover story" (see Metz & Hammer, 1993), in order to facilitate transfer.

There is evidence that DN students often focused on the numeric data itself, and did not appear to be concerned with the meaning of the numeric data (see, for instance AC4's interaction with the DN condition). This contrasts sharply with the apparent interactions of CV students who visualized scenes and appeared to recognize the movements of objects.

CHAPTER VII

CONCLUSIONS AND DIRECTIONS FOR FUTURE STUDY

Conclusions

Experimental Results: Classroom and Interview Data

All classes that received the CV treatment showed statistically significant gains on the relative motion test. All classes that received the DN treatment showed statistically significant gains on the relative motion test. There was no statistically significant difference between the honors class that received the DN treatment and the honors class that received the CV treatment. Based on the accuracy of their predictions, students in the DN condition had more difficulty with the treatment than their CV condition counterparts.

Based upon the clear difficulties encountered by students when attempting to understand relative motion (see review at the beginning of this document), it is not surprising that these short interventions did not produce large gains. In Camp, et al. (1994) approximately one week is devoted to relative motion instruction versus the one day of instruction in these studies. Similarly, to explain the lack of a statistically significant difference between classroom treatments it may be noted that, from a design standpoint, the two interventions were extremely similar. The same computer simulation was used in both; both involved working with a partner; both involved predict-observe-explain activities.

Three factors singly or in combination may have caused the CV and DN conditions to perform similarly on the posttest. First, 5 of 9 pretest/posttest questions required a numeric answer; students may be able to get an answer without visualization. Second, based on protocol evidence, students may be assisted in their ability to visualize relative motion problems by interaction with the DN treatment. Third, it is possible that the effort applied to process the anomalies of incorrect predictions assisted DN students' conceptual development. This hypothesis is suggested by the observation that more students had difficulty with the DN predictions than with the CV predictions, as evidenced by a greater number of incorrect predictions among the DN students. If students seriously attempted the activities, as appears to have been the predominant case during the interviews, they had to exert effort to explain any discrepancies between their predictions and their observations.

However, it is also possible that fewer incorrect predictions were made by CV students because, in general, their learning was more gradual than the DN students' learning. In fact, the CV treatment was designed to slowly increase in difficulty. The four activities progressed from motion in one direction (in the first simulation) to motion in two directions (in the second simulation) to motion relative to multiple supporting media (in the third simulation), to motion relative to multiple supporting media with the initial motion described relative to a non-earth frame (in the fourth simulation).

As a framework to describe students' learning, I propose the terms "step-like" and "ramp-like." In learning that may be considered conceptually step-like, conceptual change occurs, or learning is marked with obstacles that the students must overcome (see figure 7.1). In learning that may be considered conceptually ramp-like, learning is apparently more gradual, with grand advances unlikely, but progress occurring nevertheless (see figure 7.2).

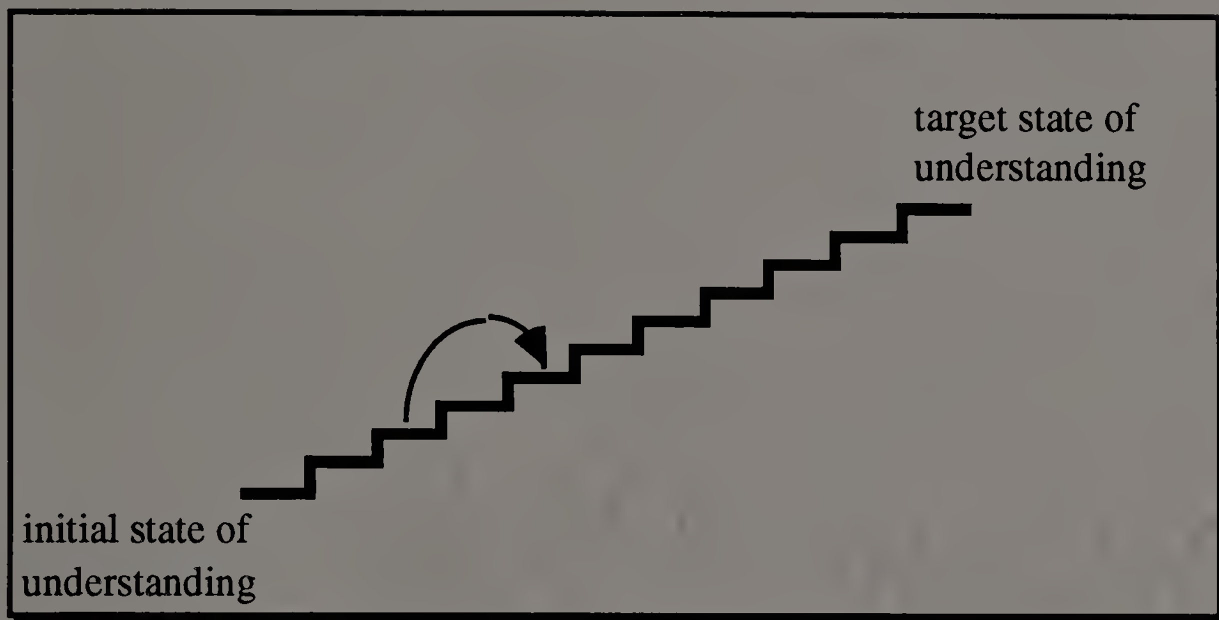


Figure 7.1

Step-like learning

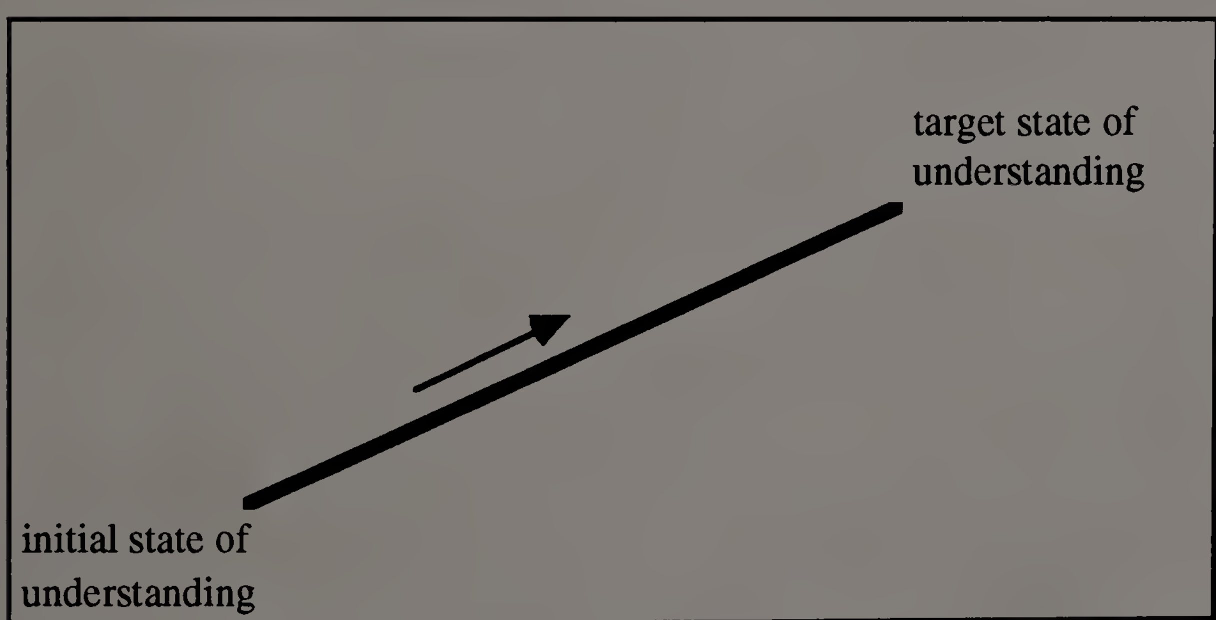


Figure 7.2

Ramp-like learning

It is possible that the learning for students in the CV case is more ramp-like than step-like, based on the lower average number of incorrect predictions made by CV students, as compared with the average number of incorrect predictions made by DN students. One difficulty with the protocol from the interviewed CV students is that of an unexpected ceiling effect; among the eight students interviewed, four answered 8 or more of the 9 pretest questions correctly.

Results: Individual Pretest/Posttest Case Studies

Below are summarized results from analysis of case study pretest and posttest protocols.

CV Pretest/Posttest. Table 7.1 below summarizes results from protocol analysis of CV interviewed students' interactions with the treatments.

Table 7.1

Summary of CV Pretest/Posttest Protocol Findings

Student	Findings
AC1 Pretest/ Posttest protocol	• gains on posttest • evidence for visualization aided by memory of simulation • evidence for cognitive conflict during treatment
AE2 Pretest/ Posttest protocol	• gains on posttest with no evidence for cognitive conflict during treatment • evidence for visualization
Posttest vs. Pretest n=8 students	t-test yielded no significant results

As a group, the interviewed CV students did not show statistically significant gains on the relative motion test. However, there is reason to believe that this was in part due to ceiling effects. (As stated before, half of the 8 interviewed students correctly answered 8 or more of the 9 pretest questions.)

During the posttest, there is evidence that AC1's memory of the computer simulations assisted visualization of target problems solved off-line. Her performance on the relative motion measure improved following instruction; her posttest score was 77% (7 of 9), compared with a pretest score of 11% (1 of 9). There is evidence that following the treatment she was better able to accurately visualize problems. Other evidence indicates that she may have abandoned a faulty epistemological commitment, namely that the only speed of an object is its speed relative to the ground. It appears clear that following the treatment, she displayed better understanding of the reference frame concept. The aforementioned factors appear to have contributed to her improved performance on the posttest.

However, AC1 did not show an expert's understanding of the arbitrariness of reference frame. Even during the posttest, she referred to objects that were "really moving," belying the possibility that while she understood that events would look differently from different frames of reference, she may still believed that objects have a "true" velocity (see Saltiel & Malgrange, 1980).

Subject AE2, like AC1, showed substantial gains on the posttest, advancing from 4 of 9 correct on the pretest to 8 of 9 correct on the posttest. She also provided evidence of improved visualization of relative motion problems following interaction with the computer simulation activities. For AE2, however, there were not signs of confusion or rapid insight during the treatment.

DN Pretest/Posttest. Table 7.2 below summarizes results from protocol analysis of DN interviewed students' interactions with the treatments.

Table 7.2

Summary of DN Pretest/Posttest Protocol Findings

Student	Findings
AF1 Pretest/ Posttest protocol	• gains on posttest • evidence for successful algorithm use • algorithm may have been developed during treatment
AF2 Pretest/ Posttest protocol	• gains on posttest • evidence for faulty algorithm use • evidence for successful algorithm use • evidence for mapping simulations to test problems • algorithm may have been developed during treatment
AC3 Pretest/ Posttest protocol	• gains on posttest • mismatch between numeric and visual representations of problems 7 & 9
AC4 Pretest/ Posttest protocol	• gains on posttest • evidence for successful use of algorithm developed during treatment
Posttest vs. Pretest n=8 students	significant posttest vs. pretest gain $p<.01$

As a group, the interviewed DN students performed better on the relative motion posttest than on the identical pretest ($p<.01$). While solving posttest problems, a number of interviewed DN students displayed evidence of algorithm use. Furthermore, there is evidence that a number of students referred to algorithms which were developed during the DN treatment (e.g., Subjects AF1, AF2 and AC4).

Subject AF2 apparently was able to construct a visual algorithm from numeric data, evidenced by his response to posttest question 5. This type of induction of a rule apparently generally occurred when DN students considered a numeric posttest question. Subject AF2's interaction with the treatment may highlight one of the difficulties associated with numeric presentation of instruction, namely that a student may appear to understand the output and may appear quite serious, yet not have an understanding of how the numeric information maps onto a visual representation. Another difficulty with such a numeric treatment was displayed by subject AC4, namely that the exercises could be solved without reflection through mechanical algorithm use (see Frank, Baker, & Herron, 1987).

All students but one among the DN interviewed students improved their performance on the relative motion test following interaction with the DN computer simulation activities. Although it appears that, based on the results of the standard control group (see chapter III), there is a practice effect, the practice effect appears to be small. Thus it can be reasoned that the performance gains were the result of interaction with the DN treatment. Additionally, it appears that the gains are not limited to one type of student (i.e., high achieving or low achieving on the pretest). However, there is evidence that during the posttest, numeric and visual representations were not coordinated by AC3. Additionally, AF2 appeared to implement a faulty algorithm when solving posttest problems. Thus, though on average students showed gains on the posttest, there are a number of difficulties which were associated with students' performance following interaction with the DN activities.

Results: Treatment Case Studies

Table 7.3 below summarizes results from protocol analysis of students' interactions with the treatments.

Table 7.3

Summary of Treatment Protocol Findings

Students	Findings
AF1 & AF2 DN Treatment protocol	• evidence that they developed and used algorithms • evidence of cognitive conflict • evidence of use of several strategies including visualization and algorithm use
AC3 & AC4 DN Treatment protocol	• evidence that they developed and used mechanical algorithms • evidence of cognitive conflict • evidence of predominantly algorithmic interaction
AA1 & AA2 DN Treatment protocol	• evidence that they developed and used algorithms • evidence of cognitive conflict • evidence of use of several strategies including visualization and algorithm use
AH1 & AH2 CV Treatment protocol	• evidence for visualization
AC1 & AC2 CV Treatment protocol	• evidence for visualization • evidence for cognitive conflict

DN Treatment. A variety of solution strategies were employed by the DN students during simulation activities. These strategies ranged from mechanical algorithm use (e.g., AC4) to a combination of visualization and algorithm use (AF1 and AF2).

As expected, there was evidence that the DN condition spurred the development and use of algorithms among several students. Even when students appeared to be capable of visualizing problems, there is evidence that they used algorithms (see, for instance, student AA1). It is hypothesized that such students were able to develop algorithms to more easily solve problems that were deemed functionally similar to problems which students had taken the effort to visualize. Other students did not display a propensity to visualize. For these students, pattern recognition and subsequent algorithm creation, application, and modification cycles appear to have been the dominant form of interaction with the treatment (see, for instance, subject AC4).

A number of DN students did not understand the meaning of 0 speed, as evidenced by their consternation with the direction information provided by the computer for objects that had 0 speed. Even when a student questioned how an object with 0 speed could have a direction (see AA1), she apparently, with the aid of her partner, came up with an explanation that was consistent with her conception of the meaning of the computer output.

Most successful interaction with the treatment appears to have involved a) understanding of the numeric output, including direction in polar degrees b) conversion of this information to a visualization. I had expected the interface to be difficult for students, believing that the polar representation would not be familiar. However, I did indicate that a direction of 0 degrees meant that an object was traveling to the right and that 180 degrees meant that an object was traveling to the left. It appears that this statement generally enabled students to understand, at least to some degree, the meaning of the numeric velocity information provided. Notably, a number of students had difficulty understanding that the direction associated with a speed of zero was erroneous. Unlike the other DN students, subjects AB1 and AB2 did not appear to satisfactorily process the polar direction information.

What to do with numeric representations that could be negative was problematic for some students. For instance, subjects AC3 and AC4 predicted that some objects' velocities would be -4 m/s, at a direction of 0 degrees. The computer output read 4 m/s at a direction of 180 degrees. AC3 and AC4 believed their answer to be wrong.

To summarize, during the DN treatment, a surprising number of strategies were employed by students. Numeric algorithm use was expected to be evidenced by students in this condition. This expectation was fulfilled in many cases. It was not expected that students would be able to construct accurate visual models of relative motion scenarios due to interaction with the DN treatment; this expectation was violated, as many students displayed evidence for visualization during the treatment. There is evidence that this treatment, which as mentioned by student AF1 during the post-posttest questionnaire (71 AF1: The computer... helped me to a certain point but you couldn't see any motion so ... it wasn't much more useful than a piece of paper basically.) did not make exceptionally good use of the potential of the computer, was able to foster accurate visualization by a number of students. Thus, a numeric treatment condition fostered visualization by some students. However, mechanical algorithms were constructed by other students.

CV Treatment. CV students had difficulty with specific predictions which were intended to foster cognitive conflict (see Dreyfus, et al., 1990) which could foster conceptual change (see Strike & Posner, 1992). For instance, the prediction for the bicycle in the first simulation proved to be problematic for subject AC1. Her difficulty with this prediction appeared to foster conceptual change; she may have changed an epistemological commitment (that the only speed of an object is its speed relative to the ground) following this event. Unlike subject AC1, AE2 did not show clear signs of cognitive conflict during the treatment.

Comparison of Incorrect Predictions

Which predictions were incorrectly made by students may give insight into differences in the type of processing used by students in each condition.

For example, in simulation 2, predictions for the black rectangle (called the black car) were most frequently incorrectly made by CV students. Predictions for the striped rectangle were most frequently incorrectly made by DN students. In this case, I hypothesize that the black car prediction was difficult for some CV students because of the direction change (the object was moving to the right in the first simulation); it is possible that anomalous feedback from the animation challenged the epistemological commitment that direction of travel is invariant. For the DN students, as seen in AC3 and AC4's interaction with simulation 2, the result of the frame change on the striped car's velocity was anomalous. Protocol evidence suggests that this was anomalous because the algorithm that students had used (i.e., to compute the velocity of an object relative to a new frame of reference, subtract the speed of the object, relative to the original frame, from the speed of the new reference frame, relative to the original frame, and reverse the direction) did not work in this case. Protocol from students AC3 and AC4 at this stage provides evidence for the anomaly, as shown below.

257. AC4: Well, all of ours matched except for the striped triangle and ahh I would guess that's probably cause ahh you add the 25 when you switched direction rather than subtract it. [indication that algorithm was incorrect]

258. AC3: Right so yep. So yeah add 25 to what?

259. AC4: To the 60.

260. AC3: Yep. Add 25 rather than subtract. Is that what the directions say?

261. AC4: Yeah we went from 180 to zero rather that from zero to 180 so that's probably why--we probably fouled up.

262. AC3: Direction--

263. AC3: So is the direction right?

264. AC4: In the direction it was. Hold on.

265. AC3: Yeah the direc--whoa direction is wrong!

266. AC4: Yeah we got the direction wrong.

267. AC3: That accounted for--for adding it instead of subtracting--subtracting instead of adding, sorry.

268. AC4: All right.

269. (pause)

270. AC3: Okay.

271. I: And what was the explanation then?

272. AC4: Umm, that we decided to change it from [direction] 180 to [direction] 0 and it should have stayed 180 and instead we subtracted 25 from 60 rather than adding.

Different predictions proved to be difficult for students in the two conditions. This may be explained by the difference between predictions that challenge the output of an algorithm versus predictions that challenge epistemological commitments. It may be reasoned, based on the greater number of difficulties encountered during the prediction phase of the treatment, that students in the DN condition had to exert more effort to make sense of the anomalous data. Based on protocol, there is evidence that students can modify algorithms following anomalous feedback (see AF1 & AF2 and AC3 & AC4's interactions with the DN treatment in chapter VI). However, for some students, such feedback may just confuse them. This may depend greatly on the level of the students, i.e., some students may become frustrated and may be unable to perform.

Comparison of Problem Solving Approaches

Two of the more striking findings of analysis of protocol were that first, there was a lack of algorithm use during the CV treatment as compared with the DN treatment. Second, the ability to remember dynamic images from the treatment and the ability to apply these memories to solution of problems was unique to students in the CV condition.

Although it is difficult to generalize the approaches used by students, there appears to be a tendency for more students in the DN condition to use algorithms to solve posttest problems.

However, the data is complex; several students appear to have used algorithms during the pretest. There is evidence that during the treatment, many DN students created algorithms to enable solution of prediction exercises. This result was expected. Similar evidence for algorithm creation and use did not appear to be present for students in the CV condition. This was also expected. Where there is evidence that CV students used algorithms following the treatment, there is little if any evidence that these algorithms were developed during the treatment. Indeed, there is evidence that for all or most CV students who used algorithms to solve posttest problems, they also used algorithms to solve pretest problems. On the contrary, there is evidence that for some DN students, algorithms were both used and revised during the treatment (see AF1 & AF2 and AC3 & AC4's interactions with the DN treatment in chapter VI).

On the posttest, there was evidence of the use of algorithms and visualization by students who had interacted with both treatments. I believe, however, that the contrast between the posttest reasoning of CV student AC1 and the posttest reasoning of DN student AF2 highlights the potential impact of the treatments. For instance, during her solution for posttest questions 7, 13 and 15, AC1 (CV treatment) appeared to use memory of the computer simulation animations to assist her visualization of the problems. AF2 (DN treatment) also referred to the computer simulations when solving posttest problems but often used algorithms to solve problems. For example, AF2 referred to a faulty algorithm when solving posttest question 5. While solving the problem, he stated his algorithm as shown in his protocol below.

> AF2: That, when there's something going, there's two things going in the same direction, if one thing, if one entity is going faster than the other, then it will appear in ah, if you put it in space, if you put in space, it would appear that the one that's going slower is actually going the other way. It would appear to another entity looking on. It would appear that the oth, that slower one is going the other way than the faster one. But really all that's happening, is ah, they're both going the same way except one is going b, ah, a speed that's increasing.

Effect of the Learning Environment

As stated above, there is much variability in students' interactions with identical treatments. Nevertheless, within these constrained activities, the types of activities performed, and the types of feedback which students received, appear to have dramatic effects on the approaches used by students when interacting with the treatments as well as when solving problems after the treatment was completed. This is of interest because the simulations used in each of the treatments were identical. Thus, it appears that how the simulations are used can have considerable impact on students' cognition and on students' performance on measures of understanding.

Based primarily on protocol analysis, the following appear to be interactions encountered with the CV treatment. Although not all interviewed students interacted in the manners shown below, there is evidence that the following appear to be modes that may be associated with interaction with the CV treatment. Some of the students' interactions appear to have been:

- using memory of simulation as framework for visualization of problems solved off-line (see AC1, AE2).
- using and developing visualization capability (see AC1, AE2, AH1 & AH2).
- reasoning on posttest problems by analogy (see AC1).
- viewing the activities as boring due to repetition (see questionnaire responses).
- encountering few anomalies (based on the average number of incorrect predictions).
- conceptual change due to processing of anomalies which may have challenged epistemological commitments (see AC1).
- ramp-like learning (hypothesized, based on the average number of incorrect predictions).

Based primarily on protocol evidence, the following appear to be interactions encountered with the DN treatment. Some of the students' interactions appear to have been:

- using and developing mechanical algorithms (see AC4).
- understanding numeric information provided (see AA1).
- when performed, effortful visualization (integration of numeric and visual representations)--<u>inferring rule from case</u> (see AA1).
- mechanical manipulation of numbers (see AC4).
- step-like learning (hypothesized based on the number of incorrect predictions).
- processing anomalous data (see AF1 & AF2; AC3 & AC4; AA1 & AA2).
- revision of algorithms following occurrence of anomalies (see AC3 & AC4).
- becoming overwhelmed (see AB1 & AB2).
- viewing the simulations as meaningless, abstract exercises (see AC4).

Below, table 7.4 details some of the interactions of students with the two treatment conditions.

Table 7.4

Student Interactions With Treatments

Interaction Category	CV Treatment	DN Treatment
visualization potential	used and developed visualization capability	used visualization during treatment
transfer	use of memory of simulation as framework for visualization	application of algorithms developed during treatment
anomalies encountered	fewer anomalies	more anomalies
	anomalies may have challenged epistemological commitments and led to conceptual change	anomalies spurred modification of algorithms
	possibly characterized by ramp-like learning	possibly characterized by step-like learning
algorithms	mechanical algorithms not developed during treatment	evidence for use and development of mechanical algorithms
numeric processing	some students encountered difficulty connecting animation to numeric problems	some students appear to have engaged in mechanical manipulation of numbers
	some students used memory of animation to assist solution of numeric problems	some students displayed evidence for understanding numeric information

Methodological Advances

In these studies, new methods for data analysis were employed. Indicators for visualization (see Clement, 1994) were used to determine the presence of visualization performed by students. Indicators for algorithm use were proposed and employed to determine incidences of algorithm use. Analysis of conversation between partners was used to provide insight into the reasoning of students when interacting with the computer simulation activities. This is significant, as conversation between partners I believe to be a more ecologically valid manner to investigate cognition than clinical interviews with a single student, as the verbalization occurs as an integral part of the activities, not as an artificial addition to the activities.

Directions for Future Study

Separation of Experimental Variables

Although interactions with the DN and CV treatments appear to have been characterized by the presence of animation (CV case) or lack of animation (DN case) and by the presence of numeric velocity information (DN case) or lack of numeric velocity information (CV case), it would be desirable to conduct future studies in which this could be determined more reliably by eliminating the context variable. (Note: CV students were given labels that provided a context for the objects on the computer simulation screens; the DN students were not given labels for the objects on the computer simulation screens.)

Investigation of the Role of Pairs

Many interviewed students, when asked what they liked most about the computer simulation activities, included in their responses that they liked working with partners. Many educational psychologists have advocated the use of collaborative activities to assist students' learning (see Levin & Druyan, 1993 for a review).

During the treatment, to serve both pedagogical and methodological goals, I encouraged students to discuss their predictions and explanations with their partners. Pedagogicially, encouraging interaction with a partner may maximize the cognitive benefits of the interaction. However, I was not completely satisfied with the interactions, as, in many cases, one student apparently dominated the interactions. Methodologically, I believed that conversations between students was a more ecologically valid way to gain insight into the students' reasoning than "thinking aloud." Once again, however, the occurrence of domination by one of the two students was problematic as it limited the amount of data that the less dominant student provided during the treatment.

If students were required to take turns, as described in Lonning (1993), some of the difficulties associated with dominance of one partner may be eliminated. However, a potential drawback is that the less dominant student may be shy and may answer some questions rather briefly--providing little data to the interviewer. This difficulty could possibly be alleviated though prompting. However, the interviewer's prompting could disrupt the flow of the students' interactions.

Another potential method for increasing the amount of, and possibly the quality of, data elucidated through paired interaction is to require students to thoroughly explain their positions (see White, 1993). In the studies described in this dissertation, the students were encouraged to discuss their ideas with their partners. However, they were not required to give detailed explanations.

In order to investigate the role of pairs on the efficacy of the treatments, it would be necessary to attempt the identical treatments in paired and individual interactions with computer simulation activities. One of the difficulties of such a study, however, is methodological. It is extremely difficult to have both students in a pair to report their thoughts in a "think aloud" fashion simultaneously for logistical and social reasons. Obviously, on the other hand, in the absence of a partner, it would be impossible to obtain peer-to-peer discussion in the individual case.

Social Interaction Between Students in Collaborative Groups

There were several different types of social interaction between students when interacting with the computer simulations. Modes of interaction ranged from passive to actively engaged. Roles that individual students appear to have taken included leader, note taker, facilitator, keyboardist, dominator, and collaborator (see Sheingold, Hawkins, & Char, 1984 for a discussion of some social interactions encountered when students participated in collaborative LOGO programming). Currently, there is no clear correlation between the roles that students played during the treatment and performance on the posttest.

Investigation of the Development and Use of Algorithms

There is evidence for student creation and use of algorithms. Algorithms were variously used by students to assist solution of pretest and posttest problems and to assist solution of prediction activities. There is evidence that during the treatment, students who used algorithms were responsive to anomalies and modified their algorithms (see AF1 & AF2, AC3 & AC4, and AA1 & AA2).

Differences Between Paper and Pencil Presentation and Computer Presentation of the DN Treatment

It could be argued that the DN condition could be presented without the aid of a computer. If that is the case, variables concerning the effect of the medium alone could be investigated by setting up a paper and pencil DN condition and a computer-based DN condition.

Visual Versus Numeric Feedback

As noted in the body of this dissertation, there is evidence that a number of students who received numeric feedback (DN condition students) were able to visualize events, possibly using numeric feedback in concert with a static graphic (the static computer screen for students in the DN condition) to form dynamic mental images, during the treatment. However, a number of DN condition students resorted to using mechanical algorithms to solve problems. In similar fashion, there is evidence that a number of students who received animated feedback (CV condition students) were able to visualize relative motion events during and after interaction with the CV treatment.

It would be informative to investigate whether DN students' use of mechanical algorithms could be attributed to specific factors within the learning environment. Additionally, it would be informative to investigate whether DN students' visualization could be attributed to specific factors within the learning environment. Similarly, further investigation of students' interactions with the CV treatment may provide information concerning factors within the environment which may facilitate visualization. Such investigations may lead to improved understanding of the effects of numeric feedback and the effects of visual feedback. Determining conditions where visual information may be more beneficial than numeric information and when numeric information may be superior to visual information can inform the investigation of, and the construction of, computer and non-computer learning environments.

A related study would involve investigation of the role of students' preferences for numeric or visual processing of problems. Salient questions would include whether and how such dispositions may be documented and how strong these dispositions may be for particular students. If such dispositions could be documented, the effect of the disposition on students' ability and willingness to use visual or numeric means to solve problems may be investigated. Additionally, how students' dispositions may be altered following interaction with visual or numeric treatments could potentially be investigated. Similarly, the effect of student aptitude on visual and numeric processing of problems could be investigated.

Indicators of Mental Imagery and Indicators of Mechanical Algorithm Use

Further investigation of the role of hand motions, kinesthetic body motions, eye movements and other potential indicators of mental imagery (see Clement, 1994; Finke, 1989) could be performed to attempt to codify interactions that lend insight into occurrences of visualization.

Similarly, indicators of mechanical algorithm use were promoted in this document. Further investigation is needed to refine these indicators. With sufficient refinement, these indicators may be used to codify students' responses to identify occurrences of the use of mechanical algorithms.

Free Exploration Versus Constrained Activity

Theorists including diSessa (1986; 1993), Papert (1980; 1993), and Horwitz, Taylor, and Barowy (1994) advocated a more open ended inquiry approach to using computer simulations (or "microworlds"). On the other hand, theorists including de Jong (1991) and Njoo and de Jong, (1993), discussed the limitations of free exploration techniques within computer simulation environments. De Jong (1991) stated,

> Learning through exploration puts high cognitive demands on learners. This may result in inefficient and ineffective learning behaviour, where students flounder and do not use the opportunities the simulation environment offers. (p. 217)

It would be beneficial to experimentally determine the conditions under which open-ended activities may be superior to more constrained activities (like those used in this study), and where more constrained activities (like predict-observe-explain) may be superior to more open-ended activities.

Educational Implications

Relative motion appears to be a domain in which many students use dynamic mental imagery to assist solution of problems, as evidenced by protocol. It appears to be possible for students to visualize scenarios during solution of diagnostic problems which contain numeric information and static, non-numeric illustrations. It appears possible for students to visualize with numeric velocity information and a static graphic. It also appears possible for students to visualize scenarios from different frames of reference following an animation. These results are encouraging, for, as Finke (1989) pointed out,

> Mental simulations can ... provide insights that might have been overlooked if one only considered formal or analytical methods in solving problems. (p. 151)

Surprisingly, numeric interventions appear to be capable of assisting students' ability to visualize problems. It is very possible that this result for some of the DN students was due to the visual nature of the domain (relative motion). Additionally, the graphics associated with the test problems may have fostered visualization for students; however, the presence of the test graphics cannot explain differences in visualization between the pretest the posttest.

Based on protocol evidence for development and use of mechanical algorithms during the DN treatment, it appears that a teacher should expect some or most students to develop algorithms for solving problems when a similar treatment is used in a similar domain. Based on the experience of a number of students in the CV condition, animations can assist students' ability to visualize and can assist students in more accurate visualization of problems.

Though various students were able to visualize during each of these events, their visualizations varied in accuracy. Additionally, the output of their visualizations may not have matched the output of their numeric processing for some students. This occurrence led to the development of theory concerning the development of mental models through the integration of visual models and numeric models. It is important to note that many times students will not realize the inconsistency between their visual and numeric models (see Linn & Songer, 1991).

Providing numeric information, as in the DN treatment, may predispose students to mechanical solution of problems (see AC4). Lack of understanding of the numeric information is problematic. (This difficulty was displayed by students AB1 & AB2.) Without graphic feedback, students may not only develop faulty numeric algorithms, but may develop faulty visual algorithms (see AF2).

Summary

As described in chapter I, difficulties and alternative conceptions associated with relative motion have been well documented. Consistent with past research findings, many students had difficulties with apparently simple one-dimensional relative motion problems, as demonstrated by performance on the pretest and the posttest and by pretest and posttest protocol evidence.

As the general consensus among researchers is that techniques which generate cognitive conflict can assist students' conceptual change (see review in chapter I), the computer simulation activities were designed to afford conceptual change via cognitive conflict. In the studies conducted, high school science students interacted with one of two sets of collaborative computer simulation activities. In the contextualized visual (CV) condition, students made predictions concerning the direction of travel of objects following a reference frame change. In the decontextualized numeric (DN) condition, students made predictions concerning the speeds of objects following a reference frame change. In the CV condition, students saw animations of events. In the DN condition, students viewed numeric velocity information. In the CV condition, students were given a context for screen icons (e.g., a black rectangle was called a car). In the DN condition students were not given a context for screen icons.

There was evidence for conceptual conflict during students' interactions with both treatment conditions. Indirect evidence of conflict was supplied by students' incorrect predictions on predict-observe-explain activities. More direct evidence of conceptual conflict was supplied by interviewed students' protocol data. Notably, certain predictions that caused difficulties for CV students appear to have contradicted common alternative conceptions of students--that direction of travel is invariant and that objects are either still or moving. On the other hand, certain predictions that caused difficulties for DN students appear to have contradicted expected output of algorithms--for instance, when speeds needed to be subtracted rather than added (see, for instance, AF1 & AF2 and AC3 & AC4 interacting with the DN treatment in chapter VI).

Following interaction with collaborative computer simulation activities which involved predict-observe-explain tasks, students in both treatment conditions improved performance on the relative motion test. No significant differences in performance on the relative motion test were identified between treatment groups. However, protocol evidence provides insight into the approaches used by students in each of the treatment conditions.

Regarding students' protocols, consistent with Clement (1994), it was possible to gain some evidence for visualization. Additionally, it appears that it may be possible to identify indicators for algorithm use. If it is possible to identify cases of visualization and cases of algorithm use, it also appears possible to identify cases where a treatment fostered visualization or fostered mechanical algorithm use.

Concerning students' interactions with the two treatments, the most salient variable appears to have been the dichotomy between numeric and visual feedback. However, it is possible that the lack of, or the presence of, a context also contributed to differences in approaches used during problem solving. As documented in chapter VI, there is evidence that DN students used algorithms to make many predictions concerning the speeds of objects following a frame of reference change. This contrasts with CV students who did not show such evidence of algorithm use during the prediction phases of the simulation activities. This may be accounted for by consideration of at least two factors, namely the effect of context and the effect of access to numeric information. For many students who used mechanical algorithms during the treatment (see for example, AC4), there is evidence that the activities became exercises without apparent meaning (see Frank et al., 1987; Niaz & Robinson, 1992). This position is supported by the apparent lack of reflection on the part of DN students, like AC4, who used algorithms during the treatment.

One of the implications of these findings is that numeric interventions can cause some students to mechanically solve exercises without reflection. However, for other students, the same numeric interventions can cause reflection concerning the appearance of the problem scenario, i.e. can foster visualization (see, for example, AA1's interaction with the treatment in chapter VI).

Visual interventions such as the CV condition appear to be far less susceptible to mechanical solution. As was the case for selected DN students, there is evidence that interaction with the CV condition fostered visualization. Additionally, there is evidence that students were able to use memory of the computer simulation animations to assist their visualization of problems solved off line (see particularly, subjects AC1 and AE2 in chapter IV). For these students, there is evidence that during the posttest, students mapped features of the computer animation onto the posttest problems. Protocol data also suggests that following interaction with the CV condition, a number of students improved their ability to visualize some relative motion test problems.

Due to the lack of animation, the DN predict-observe-explain treatment could be considered to be functionally almost identical to a paper and pencil treatment. If this holds true, and the performance of DN students and CV students are similar, then it could be argued that the effect of the presence of the computer was negligible. It would certainly be more inexpensive not to use a computer. However, though the difference between the CV honors class' performance and the DN honors class' performance on the posttest was not statistically significant, the approaches to problem solving appear to be different when individual interviewed students' protocols are analyzed. While selected DN students used algorithms to solve problems during the treatment, there is not evidence that CV students used such algorithms. Some CV students provided evidence that they remembered dynamic images and applied these memories to solution of posttest problems.

However, a number of DN students were able to visualize both before, during, and after interaction with the DN treatment. Indeed, based on evidence concerning the time spent by some interviewed students in their attempts to visualize events (see for example, AA1's interaction with the DN treatment in chapter VI), there may be evidence that students exerted more effort in visualizing events during interaction with the DN treatment than did their counterparts interacting with the CV treatment.

Thus, it appears clear that the structure of the activities performed with identical computer simulations greatly affects the interactions and the cognition of students who are working with computer simulations. Animations may provide a framework for visualization of target problems solved off-line. Both animations and the supply of numeric velocity data appear capable of prompting students' visualization. There appears to be greater variability in the cognition of students who interact with numeric computer simulation data, however. Deep understanding of topics can, it appears, be thwarted by interaction with numeric simulation data, as students may develop and implement mechanical algorithms to enable solution of exercises. On the other hand, some students may have difficulty mapping visual representations, such as those encountered in computer animations to numeric representations, such as those encountered in quantitative problems. Teachers and curriculum designers should pay careful attention to pedagogical goals when designing or implementing computer simulation activities, as the structure of the activities may significantly affect students' learning.

APPENDIX

RELATIVE MOTION PRETEST/POSTTEST

Form 09

Directions

This is a multiple choice test. Please put your name and year of graduation on the test. You may write on the test. Please circle your answers on the test itself.

Some questions will deal with the speed of one object relative to another object. Referring to the picture below, a question may deal with:

- the speed of the truck relative to the car
- the speed of the truck relative to the jogger
- the speed of the jogger relative to the tree

In this case,

- The speed of the truck relative to the car is the speed at which the truck is getting closer to the car.
- The speed of the truck relative to the jogger is the speed at which the truck is pulling away from the jogger.
- The speed of the jogger relative to the tree is the speed at which the jogger is getting closer to the tree.

For each problem, you will be given all of the information required to solve the problem.
After you have filled out your name on the test, wait for any further instructions, and start the test.

NAME: ____

YEAR OF GRADUATION: ____________________________________

SAT MATH SCORE: ____

EXPECTED GRADE IN PHYSICS THIS QUARTER: _______________________

PREVIOUS SCIENCE COURSES TAKEN: ____________________________

____

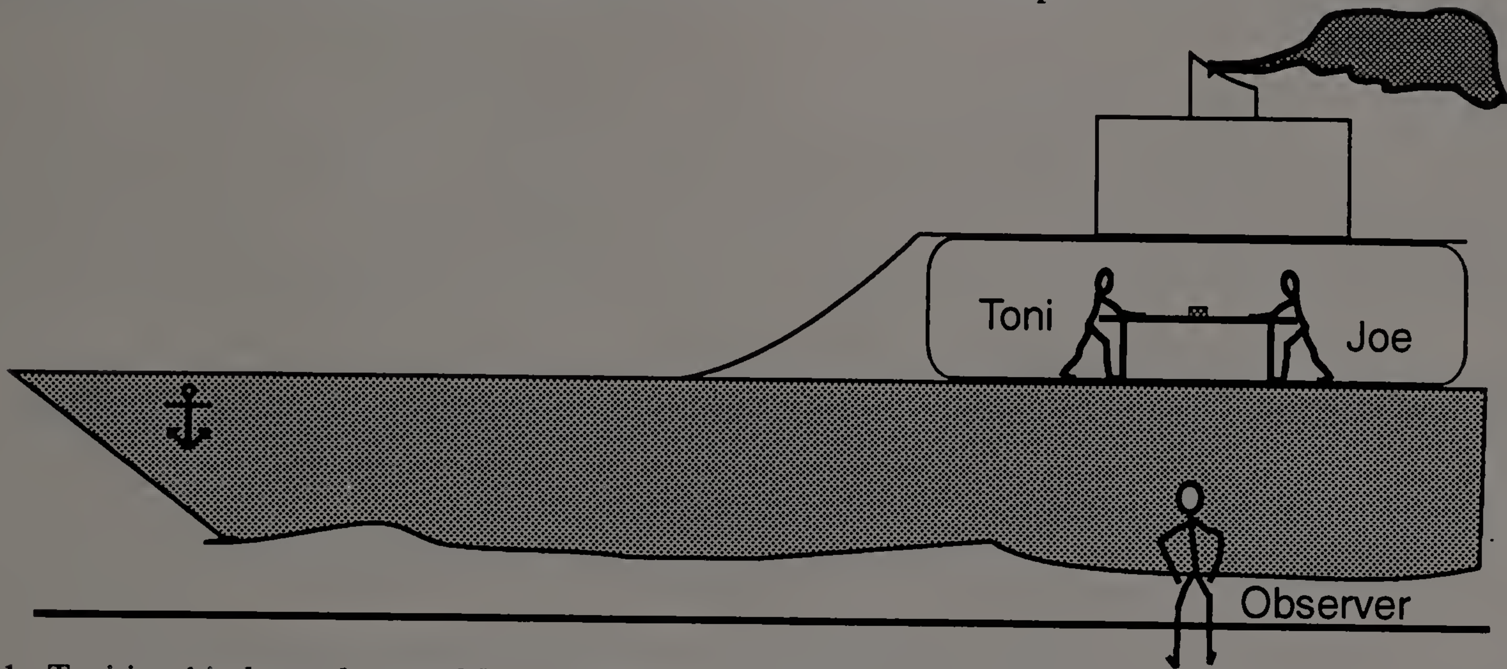
PREVIOUS MATH COURSES TAKEN (including this year): ___________________

____

____

Problems

In questions 1-6, Toni and Joe are playing air hockey in a cruise ship's game room. Relative to an observer standing on the ground, the ship is traveling to the left at 10 mph.



1. Toni just hit the puck toward Joe at a speed of 8 mph, relative to the air hockey table.

What is the speed of the puck relative to the observer on the ground?

a.) 0 mph　　b.) 5 mph　　c.) 2 mph　　d.) 18 mph　　e.) 8 mph

2. How confident are you in your answer?

a.) My answer was just a blind guess
b.) I'm not very confident in my answer
c.) I am fairly confident in my answer.
d.) I'm sure that my answer is right

3. What direction is the puck traveling relative to the observer on the ground?

a.) to the right
b.) to the left
c.) neither to the left nor to the right.

4. How confident are you in your answer?

a.) My answer was just a blind guess
b.) I'm not very confident in my answer
c.) I am fairly confident in my answer.
d.) I'm sure that my answer is right

5. Joe just hit the puck toward Toni at a speed of 8 mph, relative to the air hockey table. What is the speed of the puck relative to the observer on the ground?

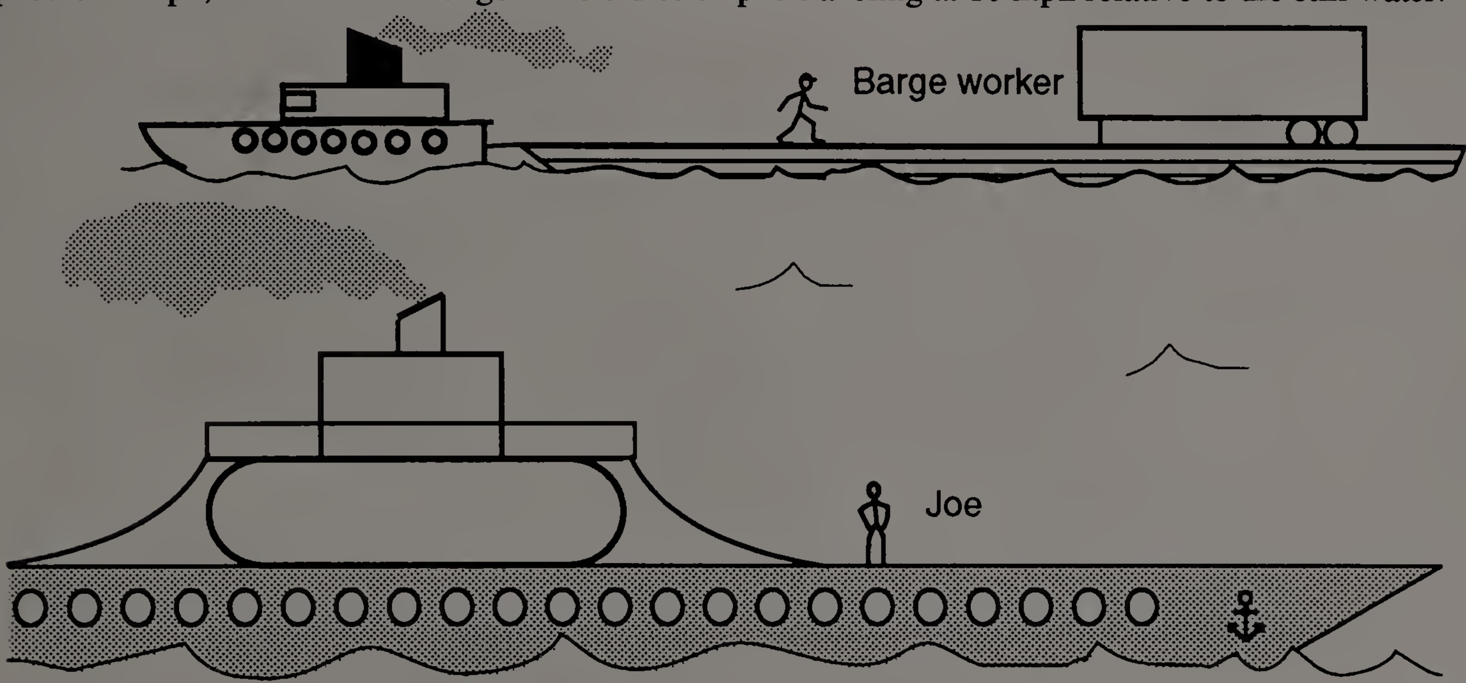
a.) 0 mph　　b.) 9 mph　　c.) 2 mph　　d.) 18 mph　　e.) 8 mph

6. How confident are you in your answer?

a.) My answer was just a blind guess
b.) I'm not very confident in my answer
c.) I am fairly confident in my answer.
d.) I'm sure that my answer is right

Numbers 7-10 refer to the scene described below:

Joe is watching a barge from the deck of the cruise ship. The barge is being pulled by a tugboat at a speed of 4 mph, relative to the still water. A barge worker is walking toward the back of the barge at a speed of 4 mph, relative to the barge. The cruise ship is traveling at 10 mph relative to the still water.



7. What is the barge worker's speed relative to the cruise ship?

a.) 6 mph b.) 10 mph c.) 4 mph d.) 0 mph e.) 8 mph

8. How confident are you in your answer?

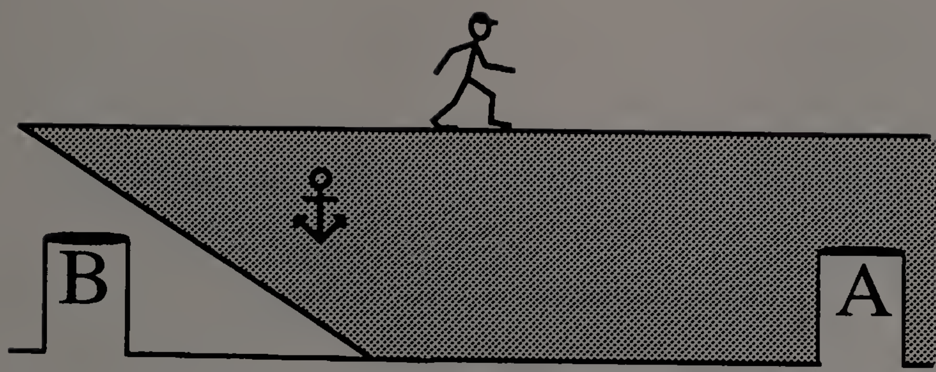
a.) My answer was just a blind guess
b.) I'm not very confident in my answer
c.) I am fairly confident in my answer.
d.) I'm sure that my answer is right

9. Joe is viewing the barge worker through a telescope. To keep the barge worker in the center of his vision, which way must he move the telescope?

a.) to the left
b.) to the right
c.) neither

10. How confident are you in your answer?

a.) My answer was just a blind guess
b.) I'm not very confident in my answer
c.) I am fairly confident in my answer.
d.) I'm sure that my answer is right



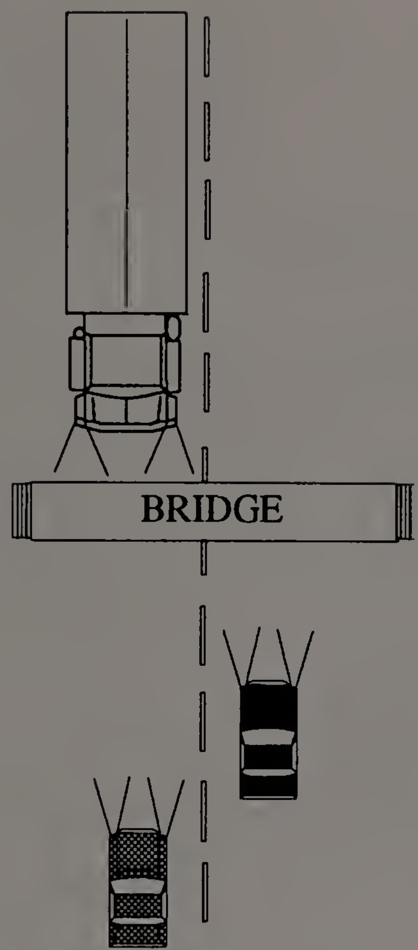
11. In the picture above, relative to the ground, the ship is going to the left at 5 mph. The sailor on the ship is walking toward the back of the ship at a speed of 4 mph, relative to the ship. To someone standing on the ground, which way is the sailor moving?

a.) toward post A
b.) toward post B
c.) toward neither post

12. How confident are you in your answer?

a.) My answer was just a blind guess
b.) I'm not very confident in my answer
c.) I am fairly confident in my answer.
d.) I'm sure that my answer is right

Numbers 13-16 refer to the picture below:



13. In the picture above, you are in the gray car. Your speedometer reads 40 mph.

What is your car's speed relative to a very low flying helicopter? Relative to the ground, the helicopter is going exactly the same direction as your car, at a speed of 200 mph.

a.) 40 mph b.) 160 mph c.) 200 mph d.) 240 mph e.) 35 mph

14. How confident are you in your answer?

a.) My answer was just a blind guess
b.) I'm not very confident in my answer
c.) I am fairly confident in my answer.
d.) I'm sure that my answer is right

15. The white truck is traveling toward your position. If the truck's speedometer reads 40 mph, what is the truck's speed relative to the helicopter?

a.) 40 mph b.) 160 mph c.) 200 mph d.) 240 mph e.) 75 mph

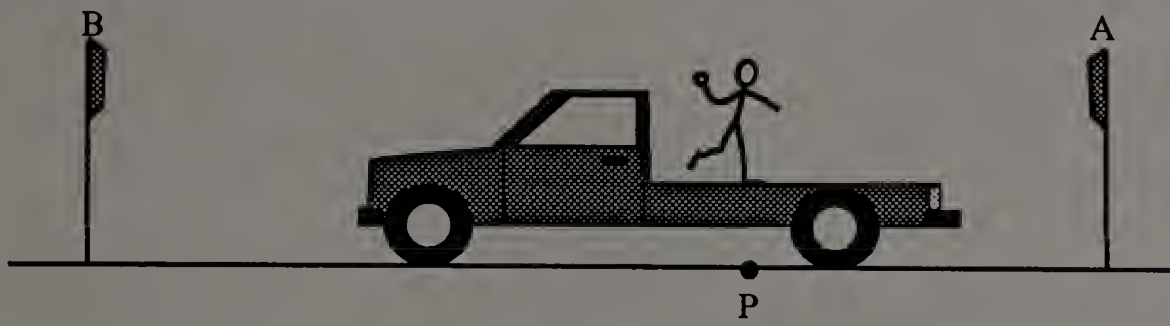
16. How confident are you in your answer?

a.) My answer was just a blind guess
b.) I'm not very confident in my answer
c.) I am fairly confident in my answer.
d.) I'm sure that my answer is right

17. Fred likes to throw snowballs, and his aim is very good. When he stands on the ground and throws as hard as he can, he can throw a snowball at 40 miles per hour, relative to the ground.

As he is riding on the back of a flat-bed truck traveling to the left at a speedometer reading of 40 mph, Fred throws a snowball as hard as he can at a road sign (A) that the truck has just passed.

He throws it just as he is over point P on the road.



Assuming his aim is good, and ignoring any effects of wind resistance, the snowball will:

a.) hit A at a speed of about 40 mph
b.) hit A at a speed much less than 40 mph
c.) hit A at a speed of about 80 mph
d.) fall and hit the ground to the left of P
e.) fall and hit the ground at P
f.) fall and hit the ground to the right of P

18. How confident are you in your answer?

a.) My answer was just a blind guess
b.) I'm not very confident in my answer
c.) I am fairly confident in my answer.
d.) I'm sure that my answer is right

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