Conceptual Development About Motion and Forces in Elementary/Middle School Students[†]

Dewey I. Dykstra, Jr.
Dept. of Physics
Boise State University
Boise, ID 83725-1570
(208) 426-3105
ddykstra@boisestate.edu

and

Dale R. Sweet
Basin School
Idaho City, ID 83631
(208) 392-6631

Abstract

In this project we have examined changes in conceptions about motion held by 4th, 6th, and 8th grade students. Instructional materials used were adapted from materials developed by the Tools for Scientific Thinking Project that make use of equipment and software originally developed in the Microcomputer-based Laboratory Project, with which students generate real-time graphs of their own motions. Prior to approximately 20 hours of instruction we asked the students to carefully describe several demonstrated accelerated motions. The majority of their descriptions were of the direction of motion only or at best “snapshot” descriptions of the motion. When asked after the instruction, the students tended to give more descriptions of these motions as continuously changing. The 4th and 6th grade students gave similar pre-instructional descriptions of the motion, yet the 4th grade students did not exhibit the degree of change in descriptions that the older students did. This suggests that with these materials or refinements of them 6th grade students and older could be expected to develop the desired changes in ideas about motion to support the development of Newtonian ideas about forces, but possibly not students younger than the 6th grade.

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The Objective of Our Work

Students' conceptions about the physical world have been studied for about two decades and we are beginning to learn about inducing high school and college students to revise their conceptions of physical phenomena. Insights gained with these older students have led us to wonder what conceptions younger students form about the world, at what ages, and what revisions might they make in these conceptions.

In particular, work has been done developing curricular materials which are aimed at inducing conceptual change in older students concerning motion (Thornton & Sokolof, 1990) and forces (Dykstra, *et al.*, 1992; Dykstra, 1996). While characteristics of the microcomputer-based laboratory (MBL) approach with children as young as sixth grade have been studied (Brasell, 1987), our work has focused on the following questions that we believe are necessary to make informed curriculum design decisions. For example:

- What are the aspects of understanding motion which appear necessary to begin to develop a Newtonian view of forces?
- At what age and under what conditions might we expect these understandings to be developed by children?
- To what extent might we expect these ideas to be developed by children in various grades in elementary school?

Without the answers to these questions, we do not know what aspects of understanding of motion are useful and at what grade levels to advocate attempting to achieve those understandings.

Experience with an approach to forces and motion developed originally by Minstrell and described by Dykstra (Dykstra, *et al.*, 1992; Dykstra, 1996) suggests strongly that students, who do not think about whether moving objects are changing their motion or not, probably do not make the distinctions between acceleration and velocity which are needed and are at a serious disadvantage when it comes to realizing the distinction between an everyday view of forces and motion and a Newtonian view. Accordingly we set out to try to see to what extent students in the 4th, 6th, and 8th grades use a distinction between speed and changing speed in their observations of motion and to what extent this might change as a result of instruction in the style of the Tools for Scientific Thinking (TST) Project at Tufts University, which is used by Dykstra in conjunction with Minstrell's approach to forces.

Experimental Design

The format of our study was to administer a pre-instruction diagnostic on motion and then conduct the instruction on motion followed by a re-administration of the diagnostic. This was repeated in two different academic years with 6th and 8th grade students and one year with 4th grade students. We then looked for evidence of similarities and differences between the groups of students with respect to pre and post instruction diagnostics and with respect to changes from pre to post instruction diagnostics.

The instructional materials were based on those from TST Project at Tufts University. These materials (Thornton & Sokolof, 1990), modified as described below, engage the students in examining graphs of their own motions which are produced on a computer screen essentially as the students are making the motions. The materials also engage the students in discussions about what they think particular examples of the graphs mean in terms of the motion which might have resulted in a particular graph.

Each type of graph, position-time, velocity-time, and acceleration-time, was introduced in laboratory activities. Students worked in groups of four or five in the 6th grade classroom, each group with a computer equipped with a motion detector, part of the MBL equipment. In these sessions they carried out activities such as:

1. Each person make a particular motion and as a group decide what are the features on the resulting graphs which relate to the motion made.
2. If you were to follow these directions for making a motion, decide as a group what a graph of that motion would look like and then test your conclusions.
3. How would you have to move to make the graph shown? Decide as a group and then test your conclusions.

In homework and class discussion, students were challenged to translate from a verbal description of motions to graphs of these motions and vice versa. The emphasis throughout was not the challenge to see who “got it right” first but on such questions as: What do we think? Why do we think so? Did it turn out the way we thought? What implications do the results have for what we originally thought? What does it seem like each type of graph is depicting? Can we use our conclusions to match graphs that the computer makes?

A Diagnostic on Motion:

We devised a diagnostic to detect how students “see” motion. It is in the form of a group-administered, demonstration interview. The class is shown three examples of moving objects, one at a time, and asked to describe the motion as completely and carefully as they can in each case. Each motion is repeated as often as the students ask and the student descriptions are individually generated on paper without discussion. The three motions were the following:

1. a soft object allowed to fall to the ground, but not allowed to bounce, which we label as “Drop” in our figures,
2. a cylinder given a gentle shove up an incline and allowed to roll up the incline and back down, which we label “Incline” in our figures, and
3. an object on the end of a string (about 60 cm) allowed to swing from left to right and back through one complete (but only one) oscillation, which we label “Swing” in our figures.

We asked students to concentrate on the time from just after the release to just before the motion was stopped in each case.

The Materials Developed for Use with the Students

The materials produced in the TST Project were intended for use by high school and college age students. We found it necessary to modify those materials to better address the needs of the age group we worked with, but the students were still carried out all of the original activities in the TST materials. (Sweet, 1991)

The basic instructions given in the worksheets, how to start the software and manipulate the apparatus were rewritten in a manner in which they might be better understood by younger students. They were also offered to the students in small or single function blocks so they could be more easily performed by students in the age group we were targeting.

The TST materials were also modified in terms of readability levels. The TST worksheets offered a readability level between the tenth and the thirteenth grade levels by the Flesch-Kincaid method. This is appropriate for their student target group. The materials were rewritten to offer a readability level of the mid-seventh grade level by the Flesch-Kincaid method, more appropriate for our student target group.

Learning Results Found in the Study

We found that the descriptions of motion that students gave in the above described diagnostic, both before or after instruction, can be categorized into three groups.

1. One type of answer could be summed up as: “It went that-a-way.” The direction of the motion was all that was mentioned; *e.g.*, “It fell down,” “It rolled up and then down,” “It swung left and then right.” In the figures that follow, the percentage of students giving “direction only” type answers are represented by the white columns.

2. The second type of answer taht we observed can be described as a “snapshot”[1] type answer. In this type of answer the direction was usually mentioned as is the speed or velocity, but never with reference to a continual change. Hence these answers looked something like: “It fell down fast,” “It rolled up fast and then down slow,” and “It swung left slow then fast and then to the right slow then fast.” There was no mention of speeding up or slowing down as a continuous process. Any speed changes were referred to only in terms of differences. In the figures that follow, the percentage of students giving this “snapshot” style answer will be a gray column.

3. The third type of answer usually mentioned direction, but it also included reference to whether or not there was continuous change in the magnitude. Answers here looked like: “It speed up as it fell,” or “It fell down and didn’t change its speed,” “It rolled up slowing down and back down speeding up,” “It swung left speeding up and slowing down and then it swung right speeding up and slowing down.” What is important here is not whether or not students were able to detect acceleration in free fall for example, but whether or not they seemed to look for and decide about whether there was continuous change or not. The percentage of students giving this “dynamic” description of the motion is represented in the figures that follow by the black column.

It is this last way of “seeing” motion that we believe to be important before students are likely to benefit from the type of lessons on forces that we believe effective at inducing conceptual change about forces in students (Dykstra, *et al.*, 1992; Dykstra, 1996).

In the Spring of one school year we were able to try our materials with a 6th and an 8th grade class. We worked with another 6th grade class in the next Fall

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[1] We are indebted to a colleague, Bob Bauman for this designation.

and the Spring after we worked with another 8th grade class and the 4th grade class. The teachers at the school were in general agreement that the original 6th and 8th grade groups which were our subjects in the first trials were better than average academically. These same two groups made bigger changes in our testing, also, so we have labeled them, “higher performance” in Figures 4 & 5. To determine to what extent the variation seen in this study represents what can be typically expected, many more class groups would have to be treated.[2] The groups represented in Figures 1 - 3 were considered more typical by their teachers and are, thus, a more conservative basis for drawing conclusions.

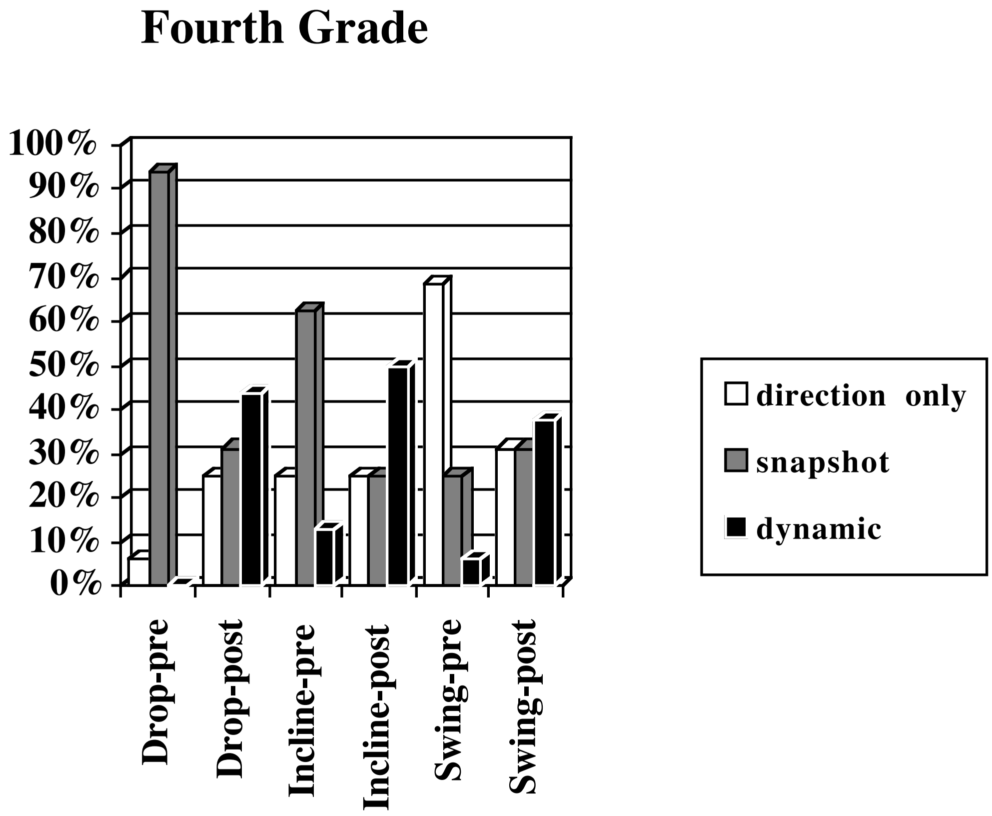

Figure 1: Results for a class of 4th grade students
There were 17 students in this class who took both the pre and post-tests.

<u>Pre-instruction Diagnostic</u>:

A scan of the figures reveals that in general the percentage of students answering with a direction only type answer decreased for all students on all tasks from pre- to post-test. Only in the 4th grade group, Figure 1, did this sort of answer increase on the drop task and remain the same on the incline task. The same is generally true for the snapshot type answers. Most importantly, in all cases the dynamic type answer increased from pre- to post-test. Thus, in all cases there is the

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[2] To do this is beyond the scope of this study, but Sweet is continuing to use these materials in his school, so he is working on generating the necessary experience to get a better answer to this question.

clear trend away from the direction only type response toward the dynamic type response. This suggests strongly that the TST based experience had the desired effect on all of the classes, but to differing degrees.

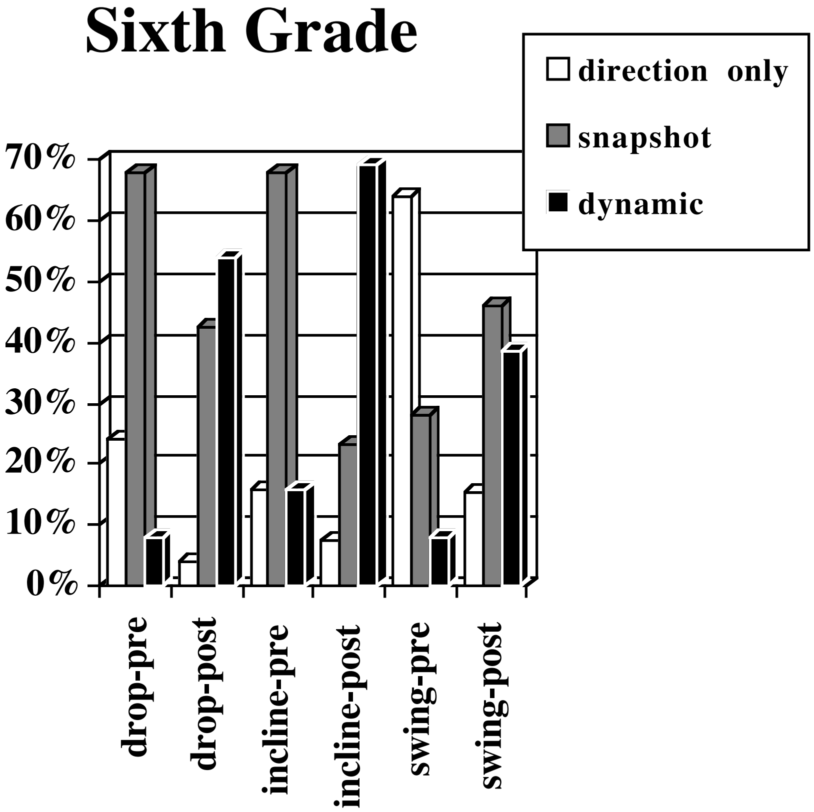

Figure 2: Results for a class of 6th grade students
There were 26 students in this class who took both the pre- and post-tests.

A comparison of Figures 1, 2 and 3 in the pre-test items suggests that the 4th and 6th grade students have a preponderance of their responses in the direction only and snapshot type categories, whereas, the 8th grade students are more evenly distributed across the categories on the pre-test tasks. This might be explained by the fact that all of the 8th grade students in this study (Figures 3 & 5) had already experienced a traditional unit of instruction on motion and forces. Yet, it is interesting to note that the 8th grade students at best exhibited dynamic type responses on only about 50% of the pre-test tasks. This low performance after traditional instruction is also seen in the TST project with older students (Thornton & Sokolof, 1990).

Post-instruction Diagnostic:

In this study not even quite 50% of the 4th grade students (see Figure 1) used a dynamic description on any task in the post-test. The task on which they demonstrated this most was the one similar to one in the instructional activities. On the other hand, while the 6th grade students (Figure 2) gave a pre-test performance hardly different than the 4th grade students, their performance on post-test tasks had noticeably more dynamic type responses than the 4th grade group. In fact comparing Figures 2 & 3 and Figures 4 & 5, the 6th to the 8th grade students, it appears that in the end the 6th grade students do about as well as the 8th grade students.

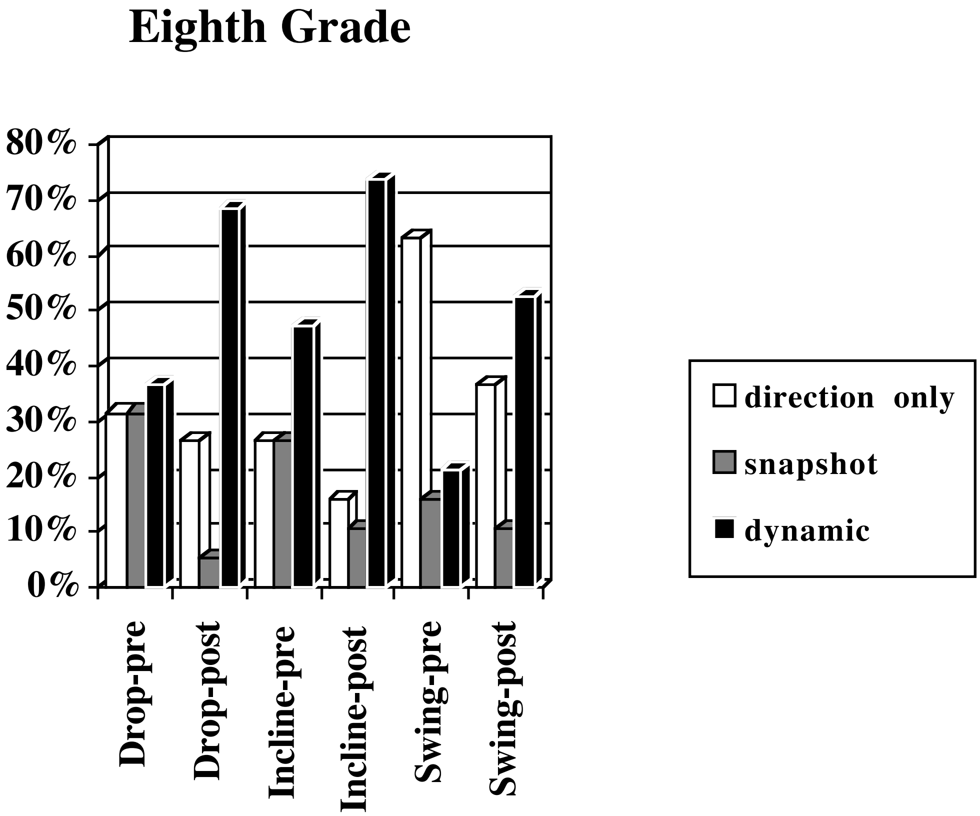

Figure 3: Results for a class of 8th grade students
There were 19 students in this class who took both the pre- and post-tests.

On the "Existence" and Significance of the "Snapshot" View of Motion:

When we started this work we were thinking only in terms of whether or not students had "a sufficiently differentiated view of motion." Did they come to look for whether or not the motion involved changing motion? On our first reading of the pre-test responses of the first group of 6th grade students, Figure 4, we did not make a distinction between the direction only and snapshot type responses, but we had trouble deciding how to divide the responses into undifferentiated motion vs. differentiated motion, including attention to change in motion. During the first pass of instruction with these 6th grade students, Dykstra, as the observer in the classroom, noticed that students had trouble with the meaning of instructions on how to move in front of the motion detectors such as:

"Start from rest, walk away from the detector while speeding up..."
or
"Repeat your motion several times until the velocity graph shows a smooth, steady increase..."

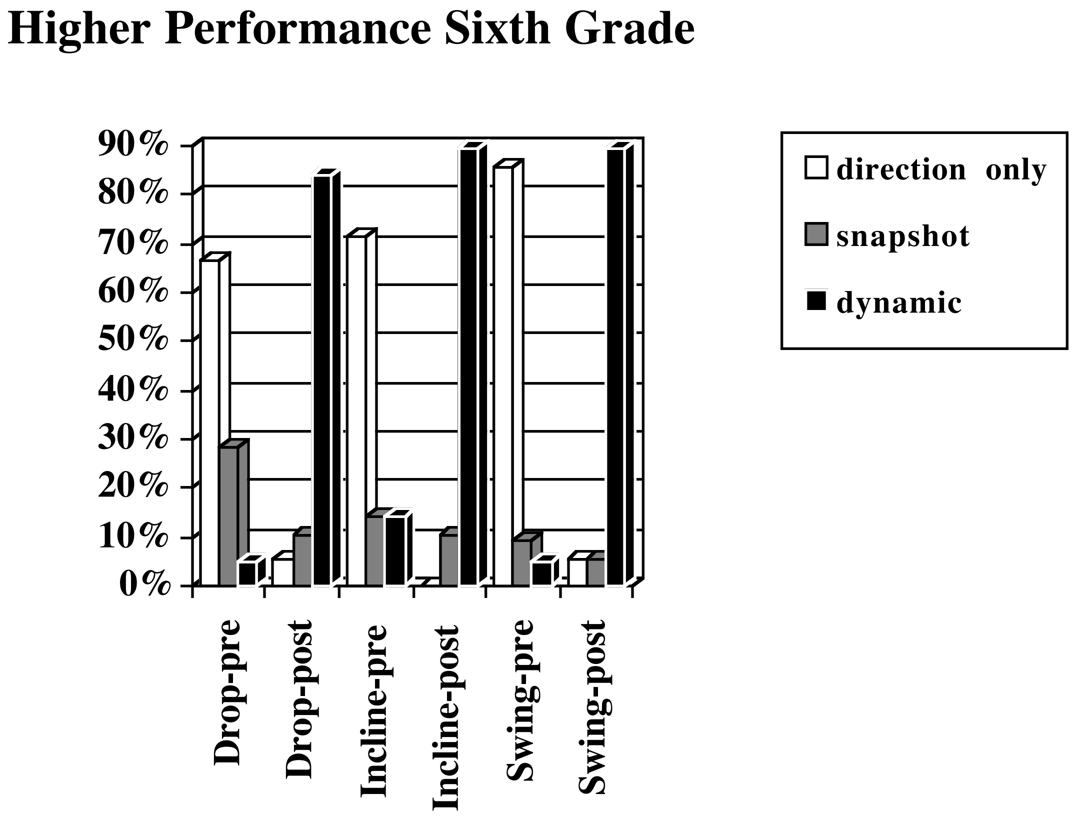

Figure 4: Results for a class of 6th grade students that made greater changes
There were 21 students in this class who took both the pre- and post-tests.

The students would walk with a steady velocity or would walk slowly and then suddenly walk with a different, greater speed. When coaching each other how to move in order to make the requested motion, they would say things like, “Walk slow and then go fast.” Having encountered that older students had problems in the same place in Dykstra’s classes, we realized that the problem may not be in the attentiveness to the instructions or in poorly written instructions. Instead, we were encountering the very issue that we had intended to address. On the pre-test tasks most students seem not to attend to such a thing as continuous change in motion. Since that may not be how they were used to thinking and seeing motion, then continuous change in motion is not obvious to them in our lab instructions or in their attempts to produce the movements.

As a result of this realization we went back and looked at the pre-test responses and at subsequent pre- and post-test responses that came in from this and other groups. We found it easier to make decisions as to how to categorize the responses, if we added the snapshot classification.

We did attempt to try to look specifically for a connection between snapshot descriptions of motion and whether or not students, when asked to make a graph of steadily increasing speed made a distance graph with one low slope to start with and then another distinct and steeper slope for the latter part of the motion.[3] We did find a few cases among the elementary students and some of Dykstra's college students who gave a "slow then fast" description and who would then draw a distance graph with two segments, the first with low slope and the second with steeper slope.

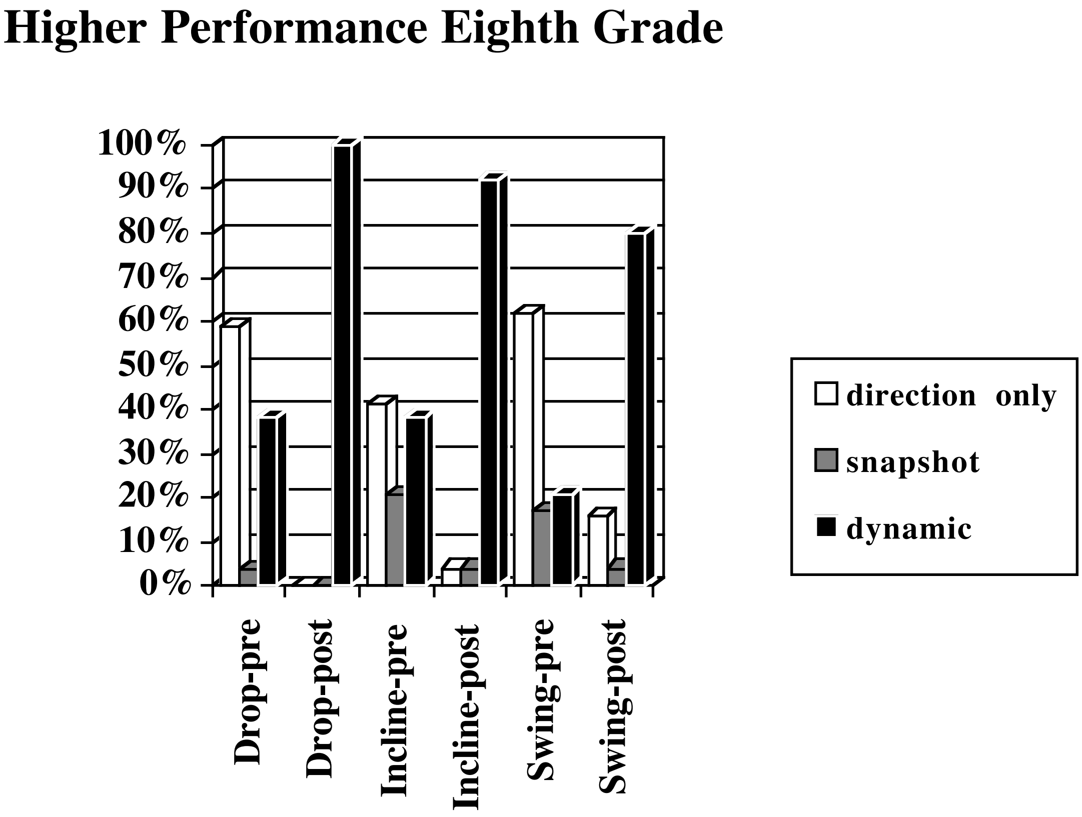

Figure 5: Results for a class of 8th grade students which made greater changes There were 26 students in this class who took both the pre- and post-tests.

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[3] To look specifically for evidence of this way of "seeing" motion we attempted an experiment in which we tried to find some correlation between students who use the "start slow, then go fast" type description and actually move in this same way in front of the motion detector. We had a difficult time getting the elementary students to translate the instructions in the materials into their own words on paper. Mostly they merely rewrote the same words they were given, so we were not convinced that we were getting *their* descriptions at that point. As such, we could not look for connections between the words and the actions they produced to make the graphs. The logistics of getting the elementary students in, one per computer station at a time, to demonstrate their ideas by actually moving to make graphs were very difficult. In the end we did not get the clear answer one way or another that we had hoped for on this issue. Should a carefully controlled experiment to test for the existence of this state of thinking about motion be carried out? Our position is that such an effort should only be made if it informs more effective teaching for conceptual change; i.e., does thinking in these terms about ways of "seeing" motion on the part of teachers have any results in the learning outcomes.

We find it significant that adding this snapshot category of description to our picture of the responses on the pre- and post-test task responses of the 4th, 6th, and 8th grade students does not seem to confuse the trends and makes it easier to categorize the responses. In addition taking the point-of-view that such a way of thinking is one notion that a number of students hold at one time or another, suggests that, rather than apply pressure to the students to "follow directions,"[4] we should view this thing that they stumble over in the instructions as a very ripe situation to get students talking to each other about what is happening which becomes an influence on those with the snapshot view to begin to question that view. We suggest that there is pedagogical relevance to the notion of a snapshot view of motion on the part of at least some students.

Evidence of a "Snapshot" View of Motion in College Student Behavior:

As we have already mentioned Dykstra had noticed that college students typically "have trouble following" these same instructions previous to the present study. To see to what extent our interpretation concerning this "snapshot" view would be supported in our observations of college students, we checked on a prediction made by the college students at the same point in their studies of motion using the TST materials. These college students are non-science majors in a conceptual physics course. Many of them are intending to be teachers of various non-science subjects at the secondary level or to be elementary school teachers. After studying distance (position) graphs and velocity graphs, they were asked the following:

> "If you made a motion in front of the detector consisting of standing at rest for one second, walking *away* from the detector while ***speeding up*** for one and one half seconds and then walking *away* while ***slowing down*** for one and one half seconds, then ***stop*** and standing at rest for one second, what would the distance and velocity graphs look like?"

Figure 6 illustrates the majority responses of 99 students to this question. Eight students made among them three additional predicted velocity graphs not shown. Figure 6A, generated by 15, students is a graph essentially matching what one would like all of the students to predict at the end of the unit of study. It illustrates a constantly increasing speed during the first part of the motion and then a constantly decreasing speed during the second part of the motion. Another was similar to this, but lacked distinct straight lines and a distinct transition from speeding up to slowing down. This prediction, Figure 6B, was drawn by 21 students. It is probable that these students were not using the same ideas as those who made the prediction in Figure 6A or not, but it seems from their sketches that their ideas about this particular motion are not as refined as the first group. The third prediction is one which appears to be one which supports our suggestion that this snapshot-view should be taken into account. Figure 6C, drawn by largest group, 40 students, consists of constant velocity punctuated by sudden changes in magnitude. There also seem to be associations between "speeding up" and larger velocity and "slowing down" and smaller velocity. The notion of continuous change

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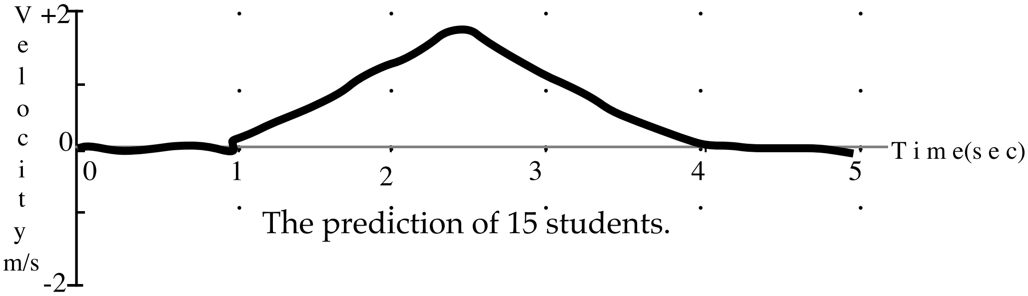
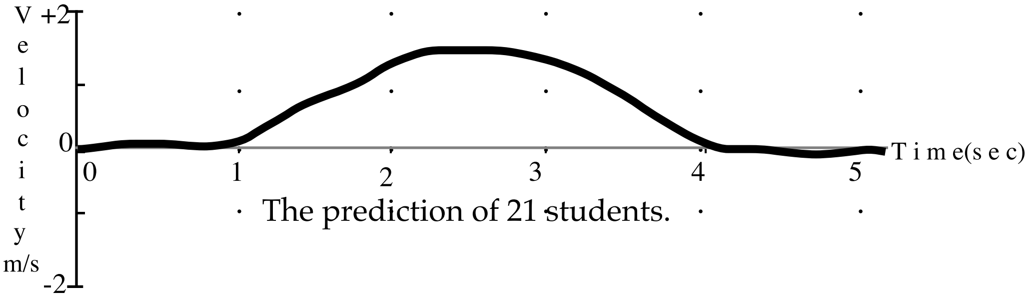
[4] We find this usually has a negative effect on their thinking in lab as it suggests there is something else they are already supposed to know, so they tend to quit trying to make sense and start trying just to guess at things in lab.

A



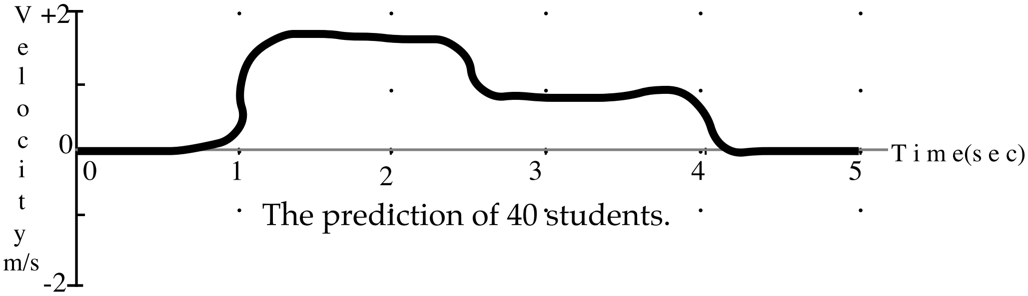
The prediction of 15 students.

B



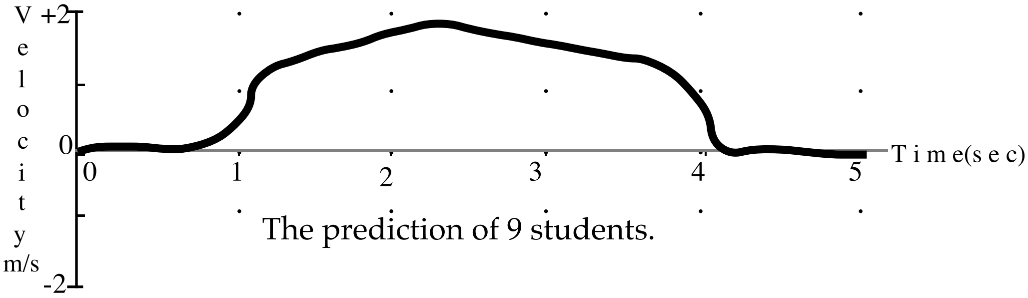
The prediction of 21 students.

C



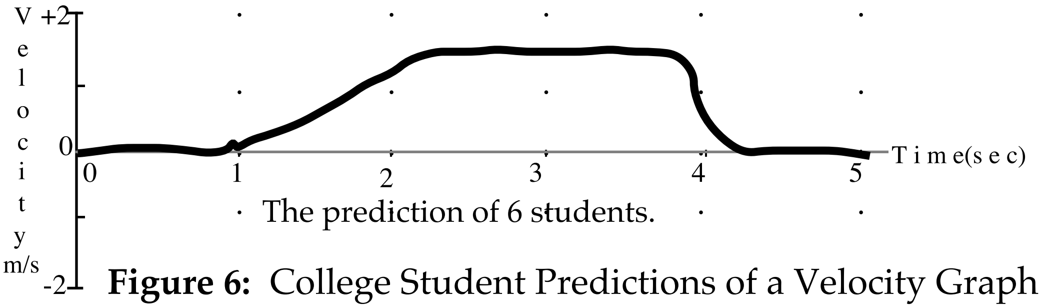
The prediction of 40 students.

D



The prediction of 9 students.

E



The prediction of 6 students.

Figure 6: College Student Predictions of a Velocity Graph

in velocity seems not to have occurred to these students even in the context of the phrases used in the instructions. There is also evidence that “stop” implies an almost instantaneous change to zero velocity as opposed to a slowing down to a stop.

We take the fact that 40 students of the 99 made the prediction illustrated in Figure 6C as additional support for our belief that the possible existence of a “snapshot” view should be taken into account in kinematics instruction and that such a view survives normal instruction well. Just about all of the students in the course described had physical science instruction including motion and forces in junior high school and possibly at some point earlier in elementary school. It should be noted that these students at this point in their study of motion have spent their time in lab and class discussion studying motions in which they were trying to move with constant velocity. Some of the students suggested that this might be why they did not draw sloping lines on the present graph. It can also be argued that the focus on constant velocity in the early part of the unit merely reinforced an outlook on motion which the students were already using; an outlook in which constantly increasing or decreasing speed is of relatively low status (Hewson and Hewson, 1992). Because of the very low status of these ideas, the students did not notice them even in the context of the specific instructions.

Finally, in observing the behavior of the college students on this issue, it occurred to us that one might understand why continuously changing speed might be of low status based on everyday experience. For most people most of the time, the focus of attention is to get up to some speed and then maintain it to the end of a trip. This would apply to walking and vehicular transportation. If one needed to get “there” faster, then one tries to travel faster, but not with continuously changing speed, just a shift in speed instead. Similarly for situations in which one can move at a more leisurely pace. In typical everyday experience we need pay little attention to the details of getting up to speed or stopping, except maybe to save some fuel by moderating our foot on the “gas” pedal in the car. This start up and stopping portion of the motion is of extremely short duration compared to the total time traveled. Hence, if the exact details of speeding up or slowing down are generally not a matter of concern for most people ever nor is it ever the object of their attention as a process to be studied, then why should we expect the idea of continuously speeding up or slowing down as a process itself to be “cued” by a phrase such as “speeding up” or “slowing down” either for the purpose of sketching it on a graph or for making a motion which consists wholely of such a motion?

Some Observations About Elementary Students and Forces:

Although limited for time[5] we were able to attempt some work with the 6th grade students on forces. Our approach was patterned after the lessons described briefly in the appendix of an article by Dykstra, Boyle and Monarch (1992) and more extensively in narrative form by Dykstra (1996) elsewhere. These lessons are the result of Dykstra’s previous work with Jim Minstrell.

The similarities in the ways with which these students approached the ideas and the differences in the ways with which these students approached the ideas compared to ways with which college and high school students approach the same ideas we find to be significant. In particular, in the student discussion in which they

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[5] We found that by the time we had gotten through studying motion, enough time had elapsed that the teachers felt that they could not give us much more time with their students, except for Sweet’s class. Even there we were limited in time.

have decided that a constant force is not what causes a constant velocity because they have found that a constant force causes a constantly increasing velocity in this case, the 6th grade students came up with the same alternative that the older students do as a possible explanation. Both groups decide to seriously consider a decreasing force as what causes a constant velocity. But, while the older students reason their way through this idea based on what they have already observed, we found that the 6th grade students seemed to need to actually try creating a decreasing force situation and see what happens.[6]

We tried this by setting up an apparatus in which a cart was pulled along a horizontal surface by a falling cup full of water attached to it through a pulley system. The cup had a hole in the bottom through which the water was allowed to flow once the whole system was released to move. This method was generated by the students when we invited them to invent a method of testing their ideas. The students agreed that what they could see in the force and acceleration graphs was that with this decreasing force a decreasing acceleration was the result.

Unfortunately, this was as far as we had time to go with the students. It occurs to us that the younger students will need to try more things to decide that certain possibilities are not realized where a number of the older students are able to reason their way through as to why certain possibilities are not likely

Problems Encountered in this Study

Frequently, the time assignment for science in the elementary classroom is on the order of 30 minutes per day and the number of topics to be covered in the year are actually quite large in the typical curricula. Both of these conditions in one way or another posed problems for our work. Luckily we worked with a 4th and an 8th grade teacher who were at least sympathetic with our goals and who trusted that our efforts would not be to the detriment of their students. Both teachers seemed to appreciate the value of a more in-depth approach for their students. A lot of juggling had to be done to arrange to have the students for 1 to 1.5 hours on several days each week for several weeks.

An interesting side issue is that such long time periods are not normally considered appropriate for the attention span of the students. Yet, the longer time frames were for lab activities and the students were usually not ready to quit when the time was up in these longer periods. This sort of instruction, when things are going well, engages the students, but it takes longer blocks of time and involves looking at fewer things in more depth.

Problems of short term interventions in the classroom:

The classroom culture consistent with the approach to the instruction we attempted is different than the traditional. In the traditional classroom, knowledge comes from the teacher and the students are to act as attentive recipients of this knowledge. Typical student verbal behavior is aimed at guessing what the teacher wants to be said and eliciting cues, clues, or validation from the teacher. Cautious students only speak when they are sure they are right and are waiting for the "smart" students to speak. Less cautious students are busy guessing and checking the teacher for validation.

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[6] Might this experience also help some of the older students? We expect the answer is yes.

The framework for instruction with which we were working is very different. The intent is that students focus on ideas that they and their peers have expressed and on observations that have been made. The students are to consider what they have seen and heard, sifting through it all and deciding what makes the most sense. The teacher is not the source of knowledge or of validation.

Some readers may quickly jump to the position that elementary students cannot do this sort of "abstract" thinking. It is quite clear that this is *not* the case in the work of Wood, Cobb and Yackel (Wood, *et al.*, 1991) or Shifter and Fosnot (1993) to name just a few. Obviously, if we also held such a point of view about limitations on student thinking, we would not be attempting this work.

One of the major problems of carrying out this sort of work is the mismatch of classroom cultures. Neither the students in this study nor their teachers were openly antagonistic to the kinds of things we were having them do. Yet, we found that class discussion, in spite of our efforts, still looked and sounded more like traditional class discussion; e.g., students tending to offer their comments for validation by the teacher rather than addressing the ideas of other students. Comparing observations of this phenomenon both at the elementary school and college levels, we believe each group of students has a different set of hurdles to overcome to engage in the discussions in the manner we would wish.

It appears that the elementary students' environment is one in which they have been in school with essentially the same classmates for several years. They have an established 'pecking' order, i.e. who is "smart" and who is not so "smart." The essential features of the classroom climate remain the same year after year. Within a school year, they have predominantly one teacher all day long. Their identities are less well developed than the college students and often less independent of those around them. All of these things tend to make it more difficult for the elementary students to change their approach for a mere intervention in class. An additional problem is the students' perceptions of the importance their own teacher places on the activities and their outcomes.

The college students usually are not in class with a significant and known cohort. They seem more independent of each other, ego and personality-wise. On the other hand they have had many more years of experience with what our society thinks school should be as exemplified by class experiences in junior high and high school, as well as, other courses in college. They have learned how to function in the standard class setting well. They have well-established habits and expectations.

To see what school learning might be we must get beyond the influence of school learning as it is. What is needed is to understand how we can empower the students to shift modes for at least short periods of time, if such a thing is possible. A second way might be to find a situation in which the same students see the same teacher for a part of the day several school years running and have that teacher establish the culture we want as part of the students' expectations when they are in that teacher's class. A third way to create a classroom culture needed for the experimentation is to have established the alternative culture as the standard culture for the classroom all day long in every subject by some teacher. While this last alternative is more difficult to establish for many reasons, for those of us who believe that this type of classroom culture has merits, the idea of working to help get this kind of environment established in classrooms is one that must be pursued.

To help the reader understand our point here with respect to the young students in our study we offer an example. Middle school level students have been programmed to expect certain behaviors and procedures in a classroom as illustrated in the following typical conversation. They want to “know” the right answer. Regardless of the feelings and attitudes of their teachers, these students seem to have been programmed to believe the only right answer is the answer that is validated by the teacher. This can be seen in the following:

Student: “Mr. Sweet, I need some help.”
Teacher: “OK what’s the problem?”
Student: “Is this the right answer?”
Teacher: “Well, did you think carefully about all the information that you have?”
Student: “Yes”
Teacher: “Are you comfortable with the way you got your answer?”
Student: “Yeah, I guess so.”
Teacher: “Then have confidence in yourself and go with the answer you have.”
Student: “OK...but is it the right answer?”

Teachers need to be careful of the above scenario. Students are so programmed to look to the teacher for validation of right answers that they may often perceive the above conversation as a teacher’s unwillingness to “help” the student. This perception may be passed on to other students, teachers, administrators and parents, thus, damaging a teacher’s reputation as a willing and helpful teacher.

When one decides to teach from the perspective we have used, there is another underlying conflict that must be thought about. That is time. The time schedule necessary to allow students to negotiate taken-as-shared meaning (Cobb, 1991) often greatly exceeds the time normally allotted for a particular curricular concept. We feel that it is more important for students to engage in exercises that induce genuine thinking than having them spend time memorizing curriculum facts and terminology. School teachers often feel pressure from themselves, other teachers, parents and administration to pay attention to the lists of skills and concepts mandated as important by curriculum guides.

Conclusions and Results

Projects such as the present study give teachers the opportunity and motivation to analyze their teaching in detail. So often, in a real life classroom, one do what one does without really thinking about how one is doing it, why one is doing it or even what it is one is doing: “Open your books to page 153 and read the selection, do the worksheet that goes with the selection.” After the assignment the evaluation of the lesson is simply to mark the students’ answers on the worksheet right or wrong. In projects like the present study, teachers are motivated to think about what they wants to achieve in a particular lesson, how they might go about achieving that and why it might be an important achievement. Evaluation of a lesson in this project certainly involved the traditional marking of papers, but it also included evaluation of our own performance and how we might do things differently to come closer to achieving our goals with the students.

Considering the observations we have described above, it seems one might expect that the 6th and 8th grade students could arrive at a dynamic view of motion, but whether it is a reasonable goal for a majority of the 4th grade students is unclear. Instead one might attempt an intermediate goal relating to a more developed notion of velocity for the 4th grade students.[7] It also seems reasonable that with more experience using this teaching approach and refinement of the materials a majority of the 8th grade students, and probably of the 6th grade students, would develop the background understandings in kinematics needed support the development of Newtonian views about forces.

Also revealed in this study is an apparent intermediate view of motion, the snapshot view, in which velocities or speeds are compared between objects or for one object at different times, but without recognition of continuous change in the magnitude of the velocity or speed. Taking the view that such a way of seeing motion might exist aided in categorizing pre- and post-test responses and it provides an explanation for the difficulty that some students have with instructions to move with continuously changing speed.[8]

Some insight as to how these students might deal with issues relating to forces was gained. Given that the 4th grade students did not in general come to a dynamic view of motion, we would hesitate to recommend that the kind of issues on forces that we intend (Dykstra, *et al.*, 1992; Dykstra, 1996) be taken up with 4th grade students except on an experimental basis. We saw glimpses from the 6th and 8th grade students that Newtonian views of forces might be attained by them, but that they might need to reason more from direct experimentation than seems necessary for high school seniors or college students. Not a surprising result, but one, the evidence for which, keeps us realistic as to how learning goals might be met.

In drawing these conclusions we recognize that there are several reasons to be cautious. The number of elementary school students was small (110 total) and for the most part things were only tried once in this study of short duration. One might wonder whether the fact that the materials were at the mid-7th grade reading level had any effect on the 4th grade students' performance.

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[7] We are not in a position to specify this in any great detail as it was not a direct object of this study. There is some work describing a conception of motion that is observed in children that the speed of an object is related to how far away it is. (Cross & Pitkethley, 1988) This might constitute an object for efforts in conceptual change on motion in the primary and early intermediate grades.

[8] There is some evidence that the existence of this snapshot view of motion may contribute to other problems later in learning about physics. A colleague of ours, Jerry Touger, has reported evidence of using this view in mis-interpreting physics they are "taught" in problems they encounter involving motion through changing conditions (communication on e-mail list, PhysLrnR@listserv.boisestate.edu, October, 1995).

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