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New Standards for Teaching Middle School Science: Now That We Have Them, What Do We Do?

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Middle school science teachers are currently facing a plethora of documents describing what and how science should be taught. In some cases, the new standards represent a fresh confirmation for some teachers of what they have been doing for a long time. For others, they represent a significant departure from current curricula and will require fundamental changes in attitudes regarding what and how teachers teach and how students learn. In almost all cases, the successful transition to a student-centered active-engagement classroom will require teachers to have detailed knowledge about how their students think and the specific difficulties they encounter as they struggle to understand basic concepts. To obtain this detailed knowledge, a research group called the Laboratory for Research in Physics Education has been formed at the University of Maine. This group examines specific sections of the new science standards, developing new curricula based on the results of physics education research, collaborating with rural middle school teachers on the implementation of that curricula, and performing research in rural classrooms to assess the effectiveness of the materials and the methods. This paper will describe one such project on kinematics piloted at a rural middle school in Spring of 1996. This project is a model for how university faculty, graduate students, and K-12 teachers can work together toward the common goal of improving the teaching and learning of science.

Introduction

A steel ball rolls across a metal track as four 6th graders look on. One has her ear pressed against the table while another is reading times off a stopwatch. The teacher intervenes and asks, "Were you able to get the ball to move without speeding up or slowing down?" One student yells that it is not possible; another claims that as long as "the track is flat," the ball will stay the same speed; still another claims to have heard the ball slowing down, reasoning, "the sound of the ball changed so the speed must also be changing." Later in the week, J.W., a literacy specialist and faculty member at a local university, conducts a drama in which he plays radio talk show host to the entire class. "Hello from radio station WORO. We are here to investigate whether or not uniform motion is possible. Do you think uniform motion is possible or impossible?" He holds an imaginary microphone towards a student. The student leans forward and grabs the microphone, saying "It is not possible!" Several other students nod or yell out in agreement. J.W. grabs the microphone back: "And why do you think it is not possible? What evidence do you have?" The student pauses for a moment thinking about the question. The microphone gets passed to another student who claims that uniform motion is impossible because, "when the track was flat, we saw that the ball was slowing down." The talk show host again counters, "When you say that you SAW the ball slowing down, what were you looking at? How do you know the ball was slowing?" The student says, "It just was, I could see it!"

Finally, after several interviews, a representative from a group of girls steps forward. J.W. has to coax the young woman to speak up so that the others can hear. "I think uniform motion is possible," she states. "And why do you think it is possible?" J.W. asks. She replies, "Because we measured it. We found that if we tilted the track a bit, the time it took the ball to go the first half of the track was the same as the second half. So the ball must not be speeding up or slowing down." A group of boys yell out that the girls are wrong. Some start yelling a mantra "not possible, not possible, not possible."

J. W. restores order and asks them to stand in a line across the room. He asks students who strongly believe that uniform motion is not possible to stand at one end of the line and for students who strongly believe that uniform motion is possible to stand at the other end. He instructs

Many individuals deserve recognition for their work on this project including Chris Chilelli, Edward Prather, Lisa Morrill, and Stephanie Wheaton, as well as several good-natured substitute teachers. Deserving special recognition is Stephen Kaback, a graduate student who worked endless hours revising materials and observing students in the classroom, and Jeffrey Wilhelm, who first introduced me to Chris Chilelli and helped us to design the more creative components of the curriculum.

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students who are unsure to place themselves somewhere along the line depending on how strongly they believe one opinion or the other. About half the class moves to the end indicating that they strongly believe uniform motion does not exist or cannot be created. A few stand in the middle and a single group of four girls position themselves at the other end of the line indicating their belief that uniform motion can be created. After a few more interviews, the class decides that in order to "prove" whether or not uniform motion can be created they need to gather more convincing evidence.

Even while the interviews are taking place, small groups of students begin to slip away from the line to grab a stopwatch and a meter stick. Before long, the entire class in engaged in measuring times and distances. Several groups of students are trying to figure out the relationship between the angle of the track and the different times they measure. Later when the "line-up" is repeated, most of the class agrees that uniform motion is possible and have recorded enough evidence to support their new belief.

Background

Almost every high school and college introductory physics class begins with kinematics, the study of motion. However, recently released documents that describe new performance standards for teaching science call for the teaching of kinematics to occur in grades 5 through 8 (see, for example, *National Science Education Standards*, 1996). In high schools and universities, the traditional approach to teaching kinematics is to provide students with the standard definitions of kinematical concepts (e.g., displacement, speed, velocity, and acceleration), a few standard equations, and then to ask students to use these equations to solve word problems. If a laboratory component to the course exists, students are asked to make measurements and compare those measurements with numbers they obtained using equations. In many cases, calculated values do not agree with the measurements and a teacher has to defend theory by claiming that the equation would have worked if they had been more careful when taking their measurements.

Eventually, many students learn to disassociate the theory from the real world (Redish, Saul, & Steinberg, 1996). Some of the better students learn to fudge their numbers so that their "experiments" agree with the theory. This process (called "dry labbing" when I took introductory physics) is usually rewarded with accolades from the teacher and better grades. Some of the students with the "messed up data" are destined to repeat their measurements until they give up, determined to never take another science class as long as they live. Others learn the trick of working backwards by starting with the theory and changing the data until it "works." Teachers, particularly college physics instructors, then complain bitterly when they find students unable to answer even the most basic conceptual questions. "Kids are not as smart as they used to be," "I can tell them the answers and they still can't get it right."

Is there an alternative to this method of teaching (as telling) and learning (as remembering)? How can students be led to derive understanding through observations? The other extreme, "open inquiry" in which students are allowed to investigate freely, has also been shown to be an ineffective method for helping students develop basic concepts (see, for example, Harris & Taylor, 1983; Strike, 1975).[1] Although some teachers have given up on trying to teach basic concepts (even some of my own colleagues at the university claim that teaching for conceptual change is too difficult and not worth the effort), national, state, and local educational reform movements are calling for, and in some cases, creating laws that will require students to obtain a functional understanding of selected basic concepts before graduating from high school.[2]

One program that has been successful at helping students build conceptual frameworks is called *Physics by Inquiry*. This research-based curriculum (McDermott, 1993), developed at the University of Washington, was created to help teachers develop an understanding of basic concepts in physical science. Not intended for younger students, these materials were designed with the intent of helping teachers make better use of existing science curricula (e.g., SCIS, ESS and SAPA).[3] Some teachers, after completing a *Physics by Inquiry* course, attempt to use the same methods and approach when generating materials for their own classes. However, without the expertise in the subject area and the time necessary to develop and test new materials, these efforts are often met with frustration. These attempts to use *Physics by Inquiry* without modification for younger students has met with limited success and usually require constant intervention and teacher focused dialogs to work. Student-centered and collaborative types of cur-

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[1]During a professional development institute run by the National Science Foundation for leaders of the Statewide Systemic Initiatives (SSI), a facilitator shared examples of science curriculum outlines created by teachers during professional development workshops run by the California SSI that made use of an "open inquiry" type approach. These outlines, many of which had been used by teachers to create new materials, contained numerous reasoning and conceptual errors. This observation is consistent with that of many others who have noted that unstructured exploration, although useful at some stages of learning, usually do not help students develop an understanding of basic concepts.

[2]The term functional understanding is used to denote an ability to perform real world tasks that require the use of specific knowledge.

[3]Science Curriculum Improvement Study (SCIS), Elementary Science Study (ESS), and Science-A Process Approach (SAPA) were materials developed in the '60s through funding from the National Science Foundation.

ricula pose a particular problem at the middle school level where the issues of student maturity, varied learning abilities, and age- or gender-specific social issues easily become determining factors for what happens in the classroom.

Description of Project

During summer of 1995, a physics faculty member, a college of education faculty member, and several graduate students met with a local middle school teacher to discuss the implications of several newly released performance standards including the *National Science Education Standards*, *Benchmarks 2000*, *Maine Curriculum Framework*, and *Maine Learning Results*. These documents list specific tasks that middle school students are expected to know and be able to do. We perceived our challenge as twofold: (1) to determine if the new standards are achievable given the constraints imposed by real world classrooms and (2) to figure out how universities can best support teachers in their quest to meet these standards. When this middle school teacher asked for help in designing new materials specifically to address these new standards, we decided to make use of the conceptual frameworks provided by *Physics by Inquiry* for our initial starting point. More importantly, we hoped to use *Physics by Inquiry* as a model for how to develop effective materials using on-going classroom research.

Motivation for Choosing Kinematics

The choice of kinematics (the study of motion) as the topic for our first project was partially motivated by the inclusion of this topic in statewide academic standards recently adopted by the state legislature. These statewide standards require that middle school students use "mathematics to describe the motion of objects including speed, distance, time, and acceleration" (Maine State Department of Education, 1996). The *National Science Education Standards* further suggests that middle school students understand that "motion can be measured and represented on a graph." These guidelines imply that students should have an understanding of what is meant by the term speed, be able to find the speed of an object, and be able to represent the position of an object at different times in both mathematical form using a data table as well as in graphical form.

Research in cognitive science has shown that, in order to teach effectively, teachers and the materials they use must take into account a student's prior knowledge and beliefs (Mestre & Touger, 1989). Thus, for instruction to be effective, curriculum development must be guided by research into how students think and reason in specific content areas. Extensive research, much of which was completed during the initial development of *Physics by Inquiry*, already exists in the area of kinematics (Beichner, 1994; McDermott, Rosenquist & Van Zee, 1987; Saltiel & Malgrange, 1980; and Trowbridge & McDermott, 1980). These researchers identified numerous reasoning and conceptual difficulties that most college level students experience when learning kinematics and found that many of these difficulties were not typically addressed by standard instruction. Our research goal was to extend this knowledge of student learning to middle school students, to identify additional difficulties unique to this population, and to design instructional strategies to address these difficulties.

Description of Overall Strategy

Research and teaching experience has led us to identify four general principles we have found useful for guiding curriculum development:[4]

- Develop concepts, reasoning ability, and representational skills together in a coherent body of subject matter, in contrast to using a series of unrelated individual exercises.
- Develop an ability to connect formalism and experimental techniques of science with real world phenomena.
- Address student difficulties explicitly, especially if these difficulties are critical for future learning.
- Teach science as a process of inquiry, not as an inert body of information.

Many curriculum development projects fail as a result of not matching the materials with the needs and the abilities of both the students and the teachers (Shymansky, Kyle, & Alport, 1983). This is especially true when research, curriculum development, and instruction are viewed as separate tasks and undertaken independently of one another. Our intent, during the pilot project, was to combine these three important components.

Our primary method of research was descriptive and qualitative. Although written pretests and posttests were administered, the most useful data came from careful observations of students working in the classroom. Thus, as students worked through the exercises in small groups, faculty members, graduate students, and preservice teachers engaged small groups of students in discussions about what they were learning and listened carefully to what they were saying to each other and writing in their journals. Although some of these insights helped us to assess and modify the materials, even more important were the insights we gained about how sixth graders perceive motion and the specific

[4]These four general principles are taken from a talk given by L.C. McDermott, Director of the Physics Education Group at the University of Washington.

difficulties they encounter when trying to understand the concept of speed.

Description of the Population

The middle school chosen for the study is located in a small town in central Maine with a population of about 10,000. Although rural by national standards, the presence of a nearby university results in a population that is, by many measures, less typical than the majority of small schools in other parts of the state. For example, students from this school typically do better than average on general academic assessment tests as compared to students in other Maine schools.[5]

For this study, we focused on three 6th-grade science classes ($N = 67$). Each class consisted of between 20 and 24 students with an almost equal mix of male and female students and met daily for 42 minutes. The entire unit was completed in about 15 class periods over the course of 3 weeks.

Description of the Curriculum

The curriculum that resulted from this collaboration made use of a directed-inquiry approach where students make careful observations, providing a basis for constructing physical concepts and developing the reasoning skills necessary to apply them to other situations. During each exercise students make and discuss predictions, provide written and verbal explanations for their predictions, and then observe the phenomena directly. After each exercise, students are required to discuss what they observe with each other and are given time to resolve discrepancies through additional exercises and experiments. Throughout the unit, students are required to keep a written log of their work including the predictions and explanations of each of the other members of their group.

Role of the Instructor

In a traditional science class, teachers usually see their role as a source of information through lecturing or by providing answers to questions. In the directed-inquiry approach, the teacher tries to use Socratic-style questioning to guide students through the reasoning necessary to develop a particular concept or idea. To be successful in helping students in this way, it is imperative that the instructor have a firm understanding of the underlying conceptual framework of each exercise as well as detailed knowledge about the alternative conceptions likely to be elicited from the students. It is only with this knowledge that teachers are best able to ask students the right types of questions to help them confront and ultimately resolve inconsistencies in their own thinking. Giving out direct answers to questions that could have been arrived at through observations and reasoning does little to help a student develop important critical thinking skills (Anderson & Roth, 1989).

The Definition of Speed

Our first objective was for students to develop a functional understanding of speed through direct observation. Previous research has found that most students experience a great deal of difficulty differentiating between a quantity and a change in that quantity. We also know, from related research and teaching experience, that students have a difficult time understanding ratios and using proportional reasoning (Arons, 1983). The study of motion provides a very useful context in which to address these conceptual and reasoning difficulties. Thus, many of the exercises were designed to help students develop a physical interpretation for the ratio of two quantities. A brief explanation regarding the purpose of several key exercises from the first phase of the project are listed below.

- Make a ball move without speeding up or slowing down using only their five senses (no timers or rulers).
- Differentiate between the concept of "speeding up" and the concept of "moving fast."
- Develop and apply a quantitative criteria for knowing if something is moving with uniform motion.
- Recognize that the time it takes for an object to travel equal distances is an indication of whether or not the motion is uniform.
- Create an operational definition for uniform motion that includes a procedure for creating the motion and a test that can be used to decide if a motion is uniform or not.
- Recognize, that for uniform motion, two ratios remain constant: the distance an object travels in one unit of time and the time it takes for an object to travel one unit of distance.
- Invent a word to represent "the time it takes for an object to travel one unit of distance."
- Recognize that "the distance an object travels in one unit of time," when moving with uniform motion, is called the "speed" of an object.

Dramatization and "Real-world" Applications

Researchers have shown that knowing the individual steps and subprocesses necessary to understand a concept

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[5]Orono High School ranks 10th out of 127 statewide schools on the Maine Educational Assessment tests. This ranking was based on a 3-year average.

is not sufficient for understanding the entire complex process in a real world context (Resnick & Resnick, 1992). To engage students intellectually and emotionally in the content, students must be given an opportunity to become a part of what they are studying. This can be achieved either through dramatization and role playing (Wilhelm & Edmiston, 1997) or through applying what they have learned in a real world context.

After experiencing a classroom dramatization (the radio talk show discussion described at the beginning of this paper) students were asked to apply their understanding of speed to determine the speed of a police car as it drove past the school. A second police car used a radar gun and recorded the speed of the car.

The method of finding the speed of the police car was left completely up to each group of students. These groups had to agree on what measurements they would need to make and how they would make those measurements. Knowing that their answers would be compared to that of the radar gun as well as to the other groups provided an atmosphere of anticipation and excitement. Reporters from the local TV stations arrived at the scene and several students were interviewed. When the time came to compare the results, the students were delighted to find out that their measurements were, in general, more accurate than the radar gun. Students also felt proud when they were able to correct a reporter who incorrectly stated on the broadcast that speed was "time divided by distance."

Graphical Representations of Motion

For the next phase of the project, we decided to introduce graphical representations of motion. In order to develop the necessary concepts, we recognized that students would need to differentiate between displacement as compared to position and clock reading as compared with time interval. Graphical representations of motion require knowledge of these two additional concepts; where the object is located (called position) and the time when the object was at that position (a "time instant" or clock reading). Recognizing that many college students in introductory physics classes experience difficulty differentiating between these quantities even after instruction, we were pessimistic with regards to how far we could, or should, go with these sixth graders. Because the *National Science Education Standards* suggests that the graphing of motion should be introduced as early as the 5th grade, we decided to press on. Thus we created additional exercises to introduce the idea of a position versus time graph. A brief explanation of the key exercises in this section are listed below:

- Locate the position of a penny on top of a desk without using a ruler and then with a ruler.
- Introduce the idea that the number on the ruler next to the location of the penny can be used to locate the penny and that we call that number the "position" of the penny.
- Use highway mile markers to help students differentiate between the idea of displacement (how far an object goes) and the idea of position (where an object is located).
- Use timers and stop watches to help students differentiate between the idea of a time interval (how long an event takes) and the idea of a clock reading (an instant in time).
- Record positions and clock readings during the motion of a soccer ball (an exercise involving the entire class).
- Use their operational definitions of uniform motion to determine the motion of the ball (uniform or non-uniform) as well as the speed of the ball.
- Represent this motion using a data table and a graph of position versus time (clock reading).

For the students in the sixth-grade class, a grid with the appropriate scales already marked were given to the students. In a later version, used with eighth graders, we tried giving the students a grid without a marked scale. We found that many of these eighth graders experienced a great deal of difficulty in marking the scales. The most common error was that students tended to use the data from the table to label each increment on the grid, even though the data were not taken in equal time intervals.

Video Motion Project

For the final exercise in the unit, groups of students were required to choose a motion they were interested in and then use a video camera to record and then analyze that motion. Examples from the student projects include a galloping horse, a roller blader, a hamster rolling inside a ball, a hockey puck, a baseball player running the bases, and a dummy thrown from the roof of a building. Several groups of students created video dramas with songs or skits about "speed" or "motion." All of the video projects were essential in helping the students make connections between the concepts and real world phenomena. The projects also gave us a window into the mind of each student; how they thought about motion and how well they understood the concept of speed.

Assessment and Analysis

As a pilot project, our primary assessment tool was descriptive information obtained through individual discus-

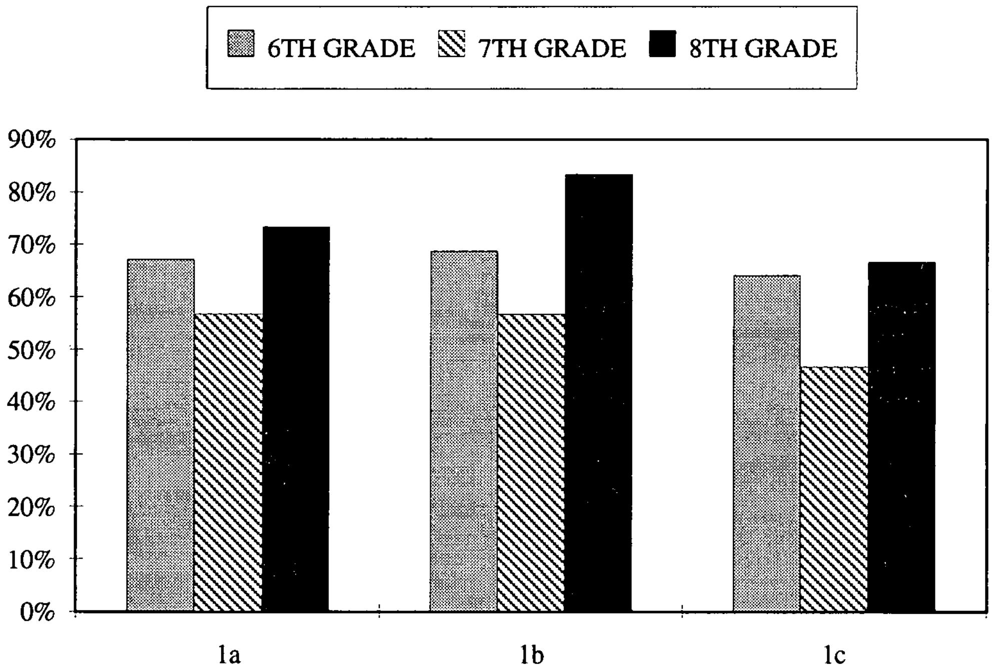


Figure 1. Motion diagnostic test: Part one (percent correct).

sions with students and observations of groups of students as they worked through the materials. In addition, we examined student portfolios containing records of each student's performance on specific tasks and independent projects.

Although many of the difficulties identified by other researchers were also prevalent among these students, a few new unexpected insights were gained. For example, we found that many sixth graders believed that the word "speed" was defined as a time interval, rather than as a ratio of distance traveled to the time necessary to travel than distance. On one pretest, one student wrote that "speed is how fast you can get something done" and another said "[speed is] how long it takes to get somewhere." Even following instruction, one group of students created a video motion project around how fast they could make five baskets using a basketball.

Another idea that came up repeatedly was that for many students speed is defined as miles per hour. Most students were not comfortable calling a quantity "speed" unless it was given in these units. For example, when given how far something traveled in meters and how long it took in seconds, most students would focus on converting to miles per hour when asked to find how fast the object was moving. Even though we agree that it is important to connect the ideas learned in a science class to situations familiar to the students (e.g., the concept of speed and "speed limits" and "speedometers"), teachers also need to be aware that students will often form incorrect generalizations from a given specific example.

In addition to the descriptive studies, we administered written tests. A pretest was given to the sixth graders before instruction and a motion diagnostic test was administered as a posttest to the sixth graders as well as to seventh- and eighth-grade students at a different school. Students from the eighth-grade class took the test after they had studied kinematics, including motion graphs. Results from the seventh-grade class that had not studied motion provided us with additional baseline data from which to compare the conceptual gain of the sixth graders. In some cases, we were able to compare the performance of these sixth graders with that of introductory college students on identical questions.

The motion diagnostic test (MDT) contains three parts. (A complete copy of the test can be obtained by writing the author of this article.) All questions were open response and, in each part, students were asked to provide a written explanation for their answer. It is our belief that in the formative stages of curriculum development and teacher preparation, descriptive and qualitative data are the most useful tools for learning how students think and learn. Thus, instead of performing a detailed numerical analysis of the written tests, we looked for general trends and attempted

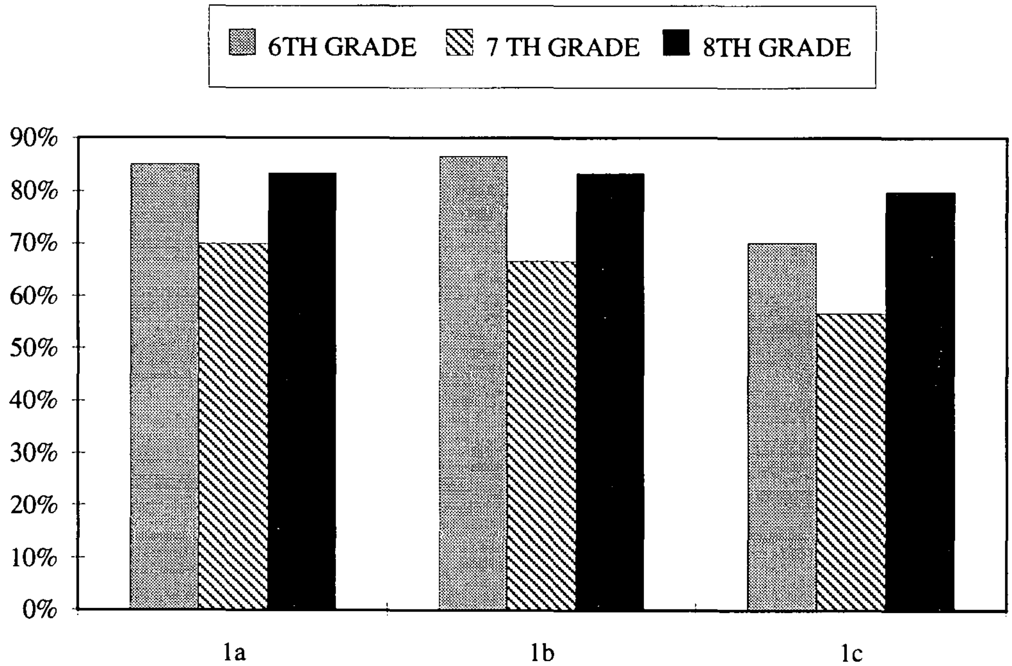


Figure 2. Motion diagnostic test: Part one (percent correct or correct analysis).

to identify common difficulties that students encountered before and after instruction.

In part one, students were given a displacement and a time interval in a familiar context (a car driving down a highway) and asked to find how far the car goes in one minute, how long it takes the car to go one mile, and to find the speed of the car (see Figure 1). Almost all students (sixth, seventh, and eighth graders) failed to recognize that the distance the car travels in one minute is called the speed of the car. Instead, when asked to find the speed of the car, most students attempted to give their answer in units of miles per hour. However, many students had difficulty with converting from miles per minute to miles per hour. For example, for some students the word "per" implied the multiplication of two quantities, rather than the ratio of two quantities. A higher percentage of eighth graders obtained the correct answer on all three questions. However, many of the sixth graders showed a correct analysis but encountered difficulties with the arithmetic (see Figure 2).

On part two of the test, students are given a table showing the times when a car passes several different mile markers. They are asked to create a graph of the motion, decide if the motion was uniform or non-uniform, find the speed of the car, interpolate between two points on the graph, and then extrapolate by making a prediction of when the car would pass a mile marker not shown in the table. As shown in Figure 3, the sixth-grade class did significantly better than the eighth graders on all sections of part two of the test (see Figure 3). For the seventh- and eighth-grade students who had not been through the kinematics unit, the most common difficulties could be traced to an inability to differentiate between position and displacement, and a clock reading and a time interval. Rather than find the distance traveled for a certain time interval, these students would incorrectly divide the position by the clock reading. Another common source of error was to include the origin of the graph as a data point, even though the origin was not at (0,0) and this data point was not included in the table. One group of eighth graders drew a bar graph instead of a line graph. This source of error could be traced to a recent mathematics class in which these students were asked to construct bar graphs in a different context.

Part three of the test involved a situation containing a uniform and a non-uniform motion: a ball rolling down an inclined track and then across a level track (see Figure 4). Non-uniform motion, which involves the concept of acceleration, was not specifically addressed in the sixth-grade class and students had difficulty extending the reasoning they had developed on this section of the test. It should be noted that this same question has been given to introductory college students, with similar results.[6]

Although not included in the K-8 section of the *National Science Education* Standards, the *Maine Learning Results* specifically states that the concept of acceleration

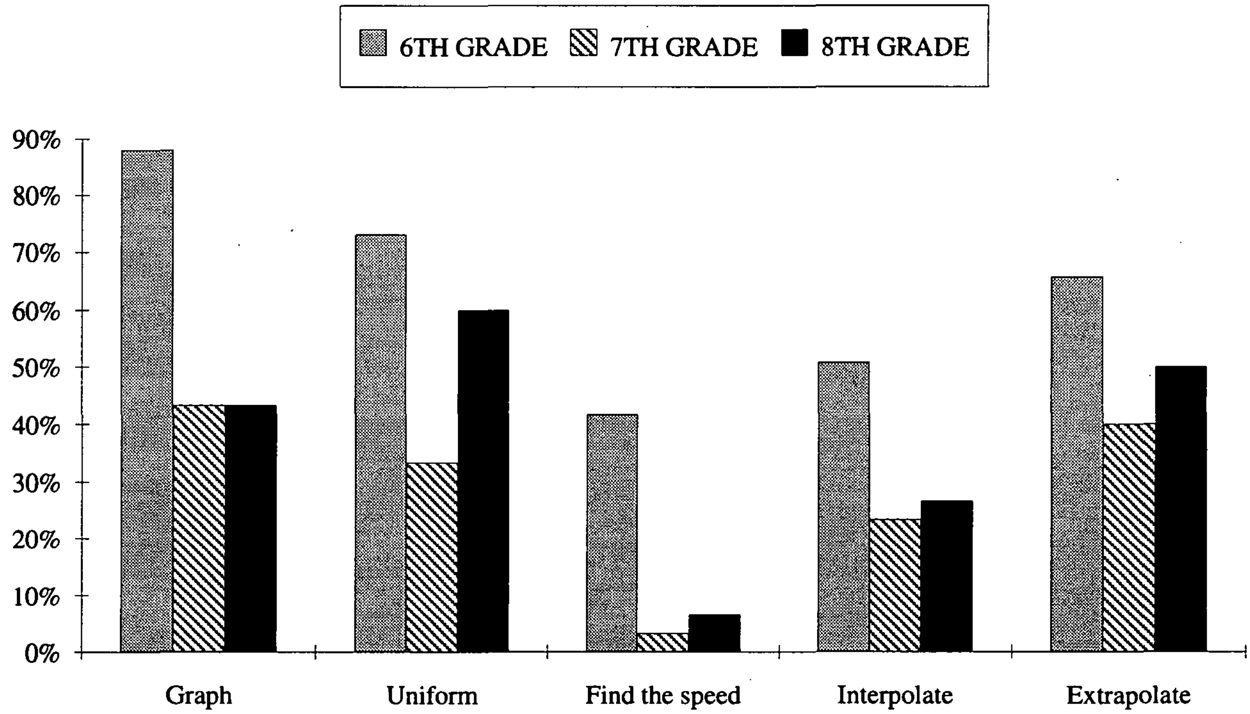


Figure 3. Motion diagnostic test: Part two (percent correct).

should be taught to middle school students. Yet, to obtain an operational understanding of acceleration, the idea of a limit (imagining very small quantities that are not zero) is necessary. This concept is particularly difficult, even for college students (Trowbridge, 1979). This leaves open the question of how best to teach the concept of acceleration to young students and whether or not this particular performance standard is appropriate for middle school students.

During the summer of 1996, the middle school teacher involved in the study presented this work at a meeting organized by the New Standards Project.[7] The primary objective of the New Standards Project is to develop curriculum assessment tools so that materials being used in different states can be judged by how well they address the overall objectives and specific performance standards given in the AAAS *Benchmarks 2000* report. The kinematics unit was determined to meet and exceed the standards for middle school science and was chosen, out of a total of 12 curricula, as one of two projects to be presented at the national meeting for the New Standards Project later that summer. One key aspect of the unit noted by the evaluators was the inclusion of numerous different representations of the content: oral, written, numerical, graphical, pictorial, and video.

Commentary

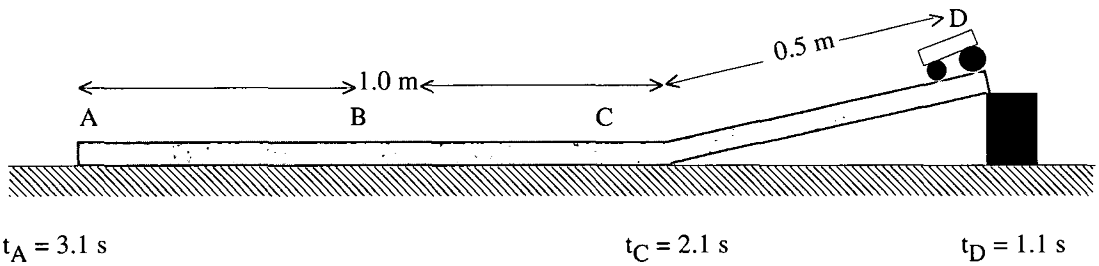
The results from the diagnostics tests are, in general, quite positive. In fact, we found that the quality and depth of the discussions between students in the sixth grade were not unlike those of college students working on similar materials. Many of the sixth-grade students showed that they were capable of reasoning formally: they considered limiting cases, asked "what if" type questions, referred directly to observations and numerical data to support inferences, and applied their understanding in new and unfamiliar contexts. (One sixth grade girl answered every single question on the diagnostic test correctly—which would put her in the top 10% of the engineering students in a recent college physics course!) It is striking that even on more quantitative questions, sixth graders using the cooperative-inquiry method performed as well as, and in some cases, better than eighth graders, even though the older students had completed a more traditional unit on kinematics with a focus on solving quantitative problems.[8] There is also some evidence to suggest that even young students who have trouble understanding fractions, may benefit from

[6]Introductory college students in a calculus based course for engineers were given the same question. Only 12% of these students were able to provide the correct answer on all four parts of the question.

[7]The New Standards Project is sponsored by the National Center on Education and the Economy and The Learning Research and Development Center at the University of Pittsburgh.

A cart is released from rest, then speeds up as it moves down an incline, and then moves with constant speed on a level segment of track. The clock reading when the cart is released at point D is 1.1 s. The cart passes point C at 2.1 s and point A at 3.1 s.

The length of the incline section of track is 50 cm and the length of the level section of track is 100 cm.



Find the speed of the cart, if possible, at each of the points A - D. If you do not have enough information to find the speed at one or more of the points, state what information you would need.

Figure 4. Motion diagnostic test: Part three (uniform and non-uniform motion).

exercises that demand the physical interpretation of a ratio in a specific context. In any case, careful attention needs to be given to the integration of the math and science curricula so that mathematical concepts can be introduced and developed in a real world context. Thus, if properly implemented, certain types of inquiry methods can lead to the development of basic concepts and fundamental skills.

Leading a group of students to successfully derive fundamental concepts through direct observation requires that the teacher have a deep understanding of the underlying conceptual framework of the discipline. A single teacher without the support of a research group would undoubtedly have a more difficult time keeping their students on task and helping them focus on the key issues.[9] Further research is necessary to identify the specific classroom management techniques required for this approach to be successful and to find better ways to support teachers who are not comfortable with the subject matter. One method of teacher support we are currently examining is use of electronic media, both e-mail and the World Wide Web, to help disseminate this work and provide on-line professional development opportunities for teachers in the more rural parts of the state. A distinct advantage of using materials based on *Physics by Inquiry* is that content-specific professional development materials already exist.

A broader implication of this study is that to successfully implement the new standards will require states to provide teachers with additional resources in the form of both instructional assistance and materials, time for professional development and curriculum planning, and classrooms that are not overcrowded. There is no magic formula or shortcut to success. Genuine learning requires careful planning, well thought out exercises, and a master teacher who possesses a keen sense of the subject matter, an infectious desire to learn, and expertise in classroom management. The positive outlook is that, given proper resources, young students can meet and exceed performance standards on tasks that have been traditionally taught to older students.

[8]Recently, the motion diagnostic test was given to twelfth graders in a high school physics class. The sixth graders performed as well as or better than the twelfth graders. On part two of the test, the sixth graders performed better than the twelfth graders on every single question.

[9]In Fall of 1996, the kinematics unit was tested in several classrooms under these very conditions. By the time you read this, we hope to have better information regarding the viability of this approach in a more typical classroom. In addition, pending funding, we hope to develop additional units on electrostatics and electric circuits.

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