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"You Don't Need to Time It, You Just Need to See It": Racing in Children's Science

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The first thing that kids did in this class, when presented with an inclined plane and a number of objects that could roll down it, was to race these objects against each other.

"Which is the winner?"
"Mine is the fastest."

The competition element was intense. It was reflected between children; but more than that, it permeated each child's view of his own work. If one thinks about a child's life- the activities, the pressures, and the rewards- it turns out to be natural to describe things in terms of races. That is the way the world is. Given such a world view, it is natural for the child to place this particular activity within his common framework and describe his results in terms of that framework.

- George Hein, *Children's science is another culture*, 1968

Background

When I first read Hein's article, I had just returned from teaching as a Peace Corps volunteer in a remote village in West Africa. His metaphor of culture took a powerful hold on me then and greatly affected both my thinking and my practice as a science teacher. I also had the good fortune at the time of my reading to have begun studies in science education at the University of Illinois. Students' ideas were 'in the air' in those days; there was a plethora of studies, talks, discussions, theses, and papers focused on students' conceptions, preconceptions, misconceptions, frameworks, paradigms, and so on. A few of those works and the authors who produced them went on to give distinctive shape to the field of science education today.

In the late 70's the Committee on Culture and Cognition at the University of Illinois published a number of reports by various educators. Jack Easley frequently discussed his work with children in mathematics. In a review of research on conservation by Piaget and others, Easley describes a 'schema' that can help explain nonconservation of length by children.

The inspiration for Piaget's research on movement and speed he once attributed to a suggestion Einstein made to him, that it would be interesting to know which developed first in children, concepts of distance and time or the concept of speed. There seems to be a connection between this question and Einstein's special theory of relativity, in which distance and time intervals are dependent on the relative velocities of the frames of reference in which they are measured. If children develop conservation of speed before they develop conservation of distance and time, it would suggest that Einstein's theory, in which the speed of light is absolute and distance and time are relative to the observer's frame of reference, is more natural than classical physics in which speed is defined in terms of absolute distance and time, taken as primitive terms. Indeed Piaget's work seems to confirm this hypothesis, but that takes us too far afield. What is relevant here is that what we might call the "racing schema" is a very early scheme that is quite strong in most four to seven-year-old children. (They race eating their cereal, doing their homework, and have a similar competitive feeling about who is taller, older, etc. as well as in the more classical sense of running, pushing toy cars, etc.)

The relevance of the racing schema for the conservation of length, number, amount to drink, etc. is that this early, comparative concept of quantitative relations is used in a wide variety of situations. It is easy for children to see the clinical interview tasks on number, quantity, length, etc. as involving a "race" or competition to which the questions are assimilated -- the judgement of who is getting ahead or who is falling behind -- regardless of what quantitative words (same, more than, less, than, etc.) and regardless of other information such as counting, measuring, and one-to-one correspondence. (Easley, 1978)

The metaphor of culture carries a rich and generative set of assumptions and associations along with any comparisons. The richness of the metaphor can also be troublesome. One user might regard a particular culture as superior to another. Another might see common elements in distinct cultures and regard cultural differences with empathy. For the teacher who "discovers" the existence of children's ideas in science, decisions about how to regard those ideas pose considerable dilemmas. Hein casts one as the choice a teacher must make between "going native" or "exporting" standard science to the culture of children's science.

The metaphor of culture is compelling. More than 20 years after Hein's article, Rosiland Driver explicitly employed the figure of speech again in connection with children and science.

Over the past 20 years science teachers and cognitive psychologists have contributed to a growing body of research literature documenting children's informal ideas about natural phenomena and the way these develop as children go through the school years. The emerging picture suggests that even children from different cultures can have similar informal models about particular phenomena. In some cases, these informal models differ from and even contradict the scientific ideas that children are presented with in school. Research suggests too that these notions may persist into adulthood alongside the science that people learn in school. An understanding of these informal models is fundamental to the development of more effective ways of teaching science. (Driver, 1991)

Armed with the idea that children's ideas could be regarded as 'sensible' in the context of their own experience and "culture," I directed my efforts as a teacher toward the search for salient and captivating phenomena to use in school science. I somehow hoped that the 'right' phenomena would help initiate a bridge from the culture of children's science to that of standard science.

The quest to understand what children notice sensitized me to particular events and situations. Hein's account of children's characteristic noticing in the case of the inclined plane was bolstered by Easley's description of the racing schema, and I found my own efforts at noticing tinged or perhaps even biased by attention to children's racing. I have even toyed with the idea of explicitly using a presumed predilection among children for races, extremes, boundaries, and limits as an organizing principle for school science activities (Frazier, 1993).

The work I present here arose from a number of biases, several of which are described above. Prominent among the biases is extensive experience of teaching science with an averred emphasis on activity and inquiry. Along with the perspective of practitioner is the belief that children's ideas in science are worthy of scrutiny. Fascination with the research into children's conceptions and practices was tempered, however, by puzzlement over the actions teachers ought to take. Reflections on the gap between children's science and standard science came while straddling the gap between my perspective as a teacher of children and a researcher into children's ideas. The reflections have been enriched, too, by recent work with preservice elementary teachers in science.

Purpose

What children notice is of primary interest to science teachers, curriculum developers, and researchers in science education. Some children adopt a particular kind of noticing when they encounter phenomena where the things to observe exhibit salient rates. Two situations are presented here where children use a racing approach to investigate dynamic physical systems. One involves third graders making water flow in tornado tubes and the other seventh graders rolling balls down inclined planes. Video-taped episodes of children's activity and their public presentation of findings are analyzed in order to elucidate the particular nature of racing. There are a number of ways in which the nature of children's racing ideas might be regarded from the perspective of a research question: as a phenomenon of noticing, an investigative technique, a cognitive schema, an epistemological stance, a mode of engagement, or a social orientation. What is troubling for the teacher is how the appearance of children's racing ideas ought to be valued in the context of the science classroom.

My purpose, then, has two facets. One is to document in some detail the appearance of children's racing in two different settings for learning science. The other is to raise questions about what a teacher should do in response to those ideas.

Methods

The data for this study are derived primarily from two video segments of children involved in science. The science camp episode involves three third grade boys investigating a toy-like device called a tornado tube (to be described subsequently). The video taped segment will be referred to in this paper as the Tornado Tubes Tape and will be described in detail shortly. The second episode to be considered in this paper comes from student presentations at the culmination of a unit on motion in seventh grade science. Four boys are recorded as they describe their findings about work with an inclined plane. This tape will be referred to as the Billiard Ball Tape.

The Tornado Tube Tape was recorded during a summer science camp described by Brown and Sinclair (1993). Several of us have studied various tapes intensively, have worked together in a video discussion group, and have presented similar data from the camp before (Brown, Beck, and Frazier, 1997; Brown, Beck, Frazier, and Rath, 1996; Rath and Brown, 1996). The tapes were made as part of an inservice teacher training course in inquiry science and were reviewed by the teachers enrolled in the course and by researchers interested in children's actions in inquiry science settings. I was associated with the project as a graduate student.

My involvement with the summer science camp tapes and the video discussion group came during a long tenure as a middle school science teacher. I was taken with the power of videotape and began to try to use video with my own classes in a variety of situations. My reasons for making the tapes in my own classes were a bit more diverse than those in the summer science camp. For my own students, tapes could be used to document their progress in an investigation. A tape could also provide them with a record of observations that could be used later for analysis and for presentations of findings. I also employed the tapes to communicate with parents, administrators, teachers, and students. Students would sometimes make a video record of a certain activity to explain their questions, procedures, and findings to another group of students who had not yet conducted a particular inquiry. I demonstrated particular points of teaching practice to my administrators and to the parents of my students. The Billiard Ball Tape is an example of a recording from my own classroom.

Comment on methods

The tapes were not made as part of a designated research program on racing. The construct of racing did 'emerge' from intense analysis of the tapes. But perhaps a long interest in children's ways of working in science prepared me to see racing in particular situations. I have developed a number of 'search images' when looking at the actions of students engaged in school science activities and discourse. On the one hand, I may be quick at seeing certain things. On the other, I may miss things I have not been prepared to see. And this is a central paradox for the scientist: How can one know what to look for if one has never seen it before?

The two episodes have several things in common. These shared characteristics may lend justification to comparisons. There are also important differences. I make the claim that the two episodes are clear examples of racing in school science settings. I also propose that the 'facts' of racing raise important questions for teachers and curriculum developers-- questions that are not easily resolved, even by close analysis of the specific situations. The propensity for racing appears to be "natural" in some sense, but in and of itself it is neither clearly beneficial nor detrimental to children's learning of target concepts in standard science. My pointing out the facts of racing and raising questions about teaching practice may seem to represent little progress since Hein posed the teacher's dilemma as making a choice between 'going native' or 'exporting' standard science to children. There may be ways, however, to foster 'cultural understanding' where children's natural propensities are used as starting points rather than as challenges to be overcome.

The Tornado Tubes Tape

A third grade class prepares for the day's activities in the summer science camp. A sense of activity accompanies the preliminary instructions delivered by the two teachers to the group of students. Around the room are plastic soft drink bottles that will be fashioned into boats and tornado tubes. The teachers ask the students to wait a bit in their explorations and then say, "We want to try to get you to think about the things you can do with bottles." One of the teachers relates an exploration he had carried out the day before when he tried to make a kind of hovercraft from an inflated balloon and a part of a bottle. He involves the class through discussion of how he developed his procedure. The teacher emphasizes observations and tells the students, "Good scientists look at every little detail." The students eventually break away from the large group to gather materials. They form small groups and are sometimes joined by one of the teachers.

At one point one of the teachers asks a boy who is working on a tornado tube, "Any ideas on how to make a better tornado?" The boy utters, "Hmmm," without much commitment. The teacher adds, "I wonder how it would change if there is more water or less water? You think that would be interesting to try?" The other teacher is surrounded by a group of six students and can be heard in the background, "Let's compare. Are they about the same? Shall we have a race? That would be one way to know who's faster?"

The tornado tubes used in the camp are made from two bottles joined together at their mouths. A short tube holds the bottles in place and a washer may be placed between the mouths of the bottles. The washer usually reduces the size of the opening and may help seal the connection. Electrical tape or duct tape can be used to join the bottles more strongly; commercially manufactured tornado tube connectors with threads matching the bottles are now available. Some of these commercial connecting tubes have a reduced opening built-in. One bottle contains some volume of water and when the device is inverted, the water tries to flow through the connected mouths. When the opening is sufficiently small, water may not flow very rapidly. Sometimes large, audible bubbles will rise to the top of the upper bottles as the water "glugs" rather than flows. If the device is moved several times in a circular direction, a vortex can form and the water will flow much more rapidly from the top reservoir into the bottom. Students at the summer science camp used food coloring to dye the water in some of the tornado tubes.

Fifty minutes after the beginning of the class, George is watching two tornado tubes. The tube on his right is colored blue and overtakes the one on his left. He holds the fast one with wide eyes. His mouth drops open. He is astonished. "Dang," he says. George talks with Tim and tries to explain a puzzle he has noticed. "Oh my God, I was right here and you were up here and you beat me." Tim does not seem particularly impressed, but George is drawn in, invited as it were to investigate this puzzling race. For the next ten minutes, George works with the tornado tubes. His activity and the increased involvement of two other boys in a shifting sphere of activity raise many questions and issues about teaching and learning science in a setting designed to promote inquiry. One particularly interesting puzzle is that while racing is proposed in the teachers' introductions as a reasonable way to compare, when George and his mates begin racing toward the end of the ten-minute segment, a teacher arrives and tries to redirect their activity. While one could value the systematic way George tests suspected variables at work in the tornado tubes, practices his newly acquired ideas, and applies his new knowledge in a context he finds meaningful, another could see the whole sequence as a poorly structured exploration which leads to school boys fooling around in science class.

For the first five minutes of the ten-minute segment, George tests a tornado tube he has constructed by comparing its performance to a tube that has been made by another student. His first four tests involve turning his tube over and waiting for some time before starting the device with blue water. I refer to this technique of starting one apparatus before the other as a head start. George's bottle is about half full; the other tornado tube with the blue water is about three quarters full. George starts a tornado tube by turning it over and giving it a series of circular movements usually in a counterclockwise direction if looking down on the end of the bottle. Sometimes the motions are more like shakes than swirls. The tube with the blue water empties in about nine or ten seconds if a vortex has been produced. George's bottle empties in about 23 or 24 seconds even with a vortex. His first two tests involve ten-second head starts. The tube with blue water empties first. In his third test, he gives his bottle a 16-second head start. His bottle empties a few seconds before the tube with blue water. George only gives his bottle a five-second head start in the next test. The bottle with colored water empties in nine seconds.

His next three tests involve some manipulation of other variables in addition to the head start. He adds more water to his bottle making it more nearly equal in volume to the tube with blue water. This may seem a puzzling move indicating that he is not finding out much about how the tornado tube works. If he is puzzled about how a tube with a head start can lose a race, why would he add more water? On the other hand, the two "competing" tubes are more nearly equal in volume. Perhaps George is looking for a threshold of effectiveness in a head start.

During these first tests, George stands with stylized postures of astonishment with his hands on his hips, his face scrunched up in contemplation of the anomalous outcome of the races. He exclaims at the result of the fifth test, "He's really beating me!" How can the blue water bottle be faster than his even when his has a head start? His mock surprise may indicate how he is coming to expect the result. For the sixth test, he says, "I'll have a big head start this time." Although the head start is ten seconds, the tube with blue colored water does not make a vortex and empties slightly after George's tube. When George notices that the tube with blue water does not empty first, he exclaims, "Hey, it's not swirled." The utterance is delivered in a kind of public, self-talk. Perhaps this self-consciousness points out what he thinks he should be noticing as important. He is engaged in investigating the factors that affect the emptying rate of the tornado tubes. Not only has he been invited into the phenomenon, but he has also accepted exploration as an appropriate mode of engagement. What enriches his approach is that he wants to win; he wants to find out what will make his tornado tube the one that empties fastest. George inadvertently gives his tube a 15-second head start in the seventh test. He realizes he has perhaps waited too long to start the tube with blue water and says, "Whoa," while looking at the camera.

George has just tested his bottle against the faster bottle with blue water. He has found the threshold for an effective head start and has varied the volume of water in order to make sure that the threshold is based on equal volumes. That is one version of what George does. George's sense of testing is perhaps conflated with the identities of the boys who 'own' the bottles. His discourse about the bottles is full of personal pronouns. "He's beating me." "I was here and you were there." But his actions did focus on the physical parameters of one bottle's emptying rate in comparison to another's. The use of 'test' here is to emphasize by way of etymology the physical emphasis of an assay, that nature does the sorting.

George hypothesizes next. He says after the seventh test, "I'll just try it without this washer." He takes out the washer and rejoins the bottles. His statement has the quality of baby-talk; it is almost submissive. It is like he is talking to an adult and invoking or portraying an innocent tentativeness. Perhaps it is the child's register for offering hypotheses. He turns his device over without the washer. He does not include the bottle with blue water. His tornado tube now empties in 14 seconds. Earlier his tube emptied consistently in a range between 23 and 25 seconds. He shakes his hands in a small gesture of accomplishment waving to some impending victory. He says, "Now the tube has some speed." It is one of the few times he does not make a personal identification with the tube. His conclusiveness supports the idea that his investigation in the earlier tests was systematically directed toward some desired outcome. George conducts three more trials. He demonstrates for one of the teachers that a tube can empty quickly without a washer. He leaves briefly after saying, "Maybe I shouldn't have this much water." He returns and his final trial with no washer and less water has his tube emptying in six seconds. The trials do not involve comparison with a control, but they do indicate a directed 'hypothesizing' and perhaps a readying for what comes next.

Tim has returned to the table. He had claimed the bottle with the blue water earlier. Shortly after George's six second emptying, Tim says, "Let's have a race," and then without much verbal warning, "Ready, set, go." George is prepared, however, and gets a head start. Another student, Fred, joins the race last but wins. Twelve contests take place in the next three minutes. Clearly the competition is between George and Fred, but Fred wins most frequently. The use of the head start as a strategy makes the races quite confusing at times. The boys display athletically ready stances and quickness of motion as they set the water swirling in their tubes. There is argument over fairness in terms of the volume of water. At one point George and Fred place their bottles side by side; the volumes are nearly equal. Fred uses a sport's announcer's voice as the tubes empty, "There mine goes. It's going fast. It's going to be close, and I won." Fred even comments on the use of the head start emphasizing the strength of his victory over the puzzle of how a bottle can come from behind. "This side is a little late even though I won again." The boys even debate on how they flip the bottles over and whether the techniques are fair. Fred says again, "I won even though he flipped it over first." George replies, "No, you didn't." Fred comes back, "Yes, I did even though you flipped yours over first." The winning has become important to George. He declares even though he has won few of the races, "I'm undefeatable." When Fred says, "I've won the most," George responds, "Last year I was." The contests differ from the tests in that they are strongly social. This usage is in harmony with the etymology. The tests are settled by nature; George was an honest judge when he was racing his bottle against the one with the blue colored water. The contests involve debate, gaining advantage, arguing over rules, and flaunting victory.

What is interesting in trying to understand and value the activity, is the ease with which George and the others shift from tests to trials to contests. The head start began as a kind of experimental control based on a threshold and became transformed into a strategy for winning. While racing was initially proposed by one of the teachers as a legitimate way to make comparisons in a science class, George and his mates move through the different modes of racing with natural ease.

A few minutes after Fred's bottle comes apart, Tim invites George to race again. This time one of the teachers is present.

Tim (to George): Here, I'll race you. Ready, set, go.
(Mrs. Roos watching)
Tim: I'll race you again. One, two, three.
9:38
Mrs. Roos: Do you think it races faster if you jiggle it more or if you just jiggle it a little?
(Tim and George are racing their tornado tubes.)
Tim: I won.
George: I won, I won.
Mrs. Roos: Tim, George, which way do you think it works better--with a lot of jiggling or just a little.
Tim: A lot. Ready, set, go.
(Fred has returned and Tim and George are racing again.)
Fred: That one was a tie.
Tim: This one's a tie.
George: Yeahhh. One tie, two wins. Woooo.
Mrs. Roos: I have an idea. One of you could watch the clock up there, and there's a red second hand. And you could do it two times. You could try one time jiggling it a lot and see how many seconds it takes, and then try one time just letting it go by itself.
Tim: OK (noncommittally).
Mrs. Ross: And see how many seconds it takes, and you could see different ways to see which one would make it go the fastest.
Tim: Wait a minute, wait a minute, wait a minute.
Fred (imitating): Wait a minute, wait a minute, wait a minute.
9:39:28
Tim: Ready, set, go.

The last race takes place and then Tim and George complete a few parallel runs. There is no timing. Soon the boys leave the table. No racing occurs during the remainder of the session.

Several features of this extended episode stand out in regard to the discussion of racing. One is that racing is clearly taking place. The children and their teachers explicitly use the word 'race.' The language of starting a race, winning, and losing is repeatedly used as well. Second, George's noticing of an apparent anomaly becomes a primary tool he subsequently used to investigate the parameters of performance of the device. He expresses puzzlement at how a tube with more water and a late start can still overtake and 'beat' the tube that was started first with less water. George employs the head start as a way of amplifying the effect any of his manipulations might have on the emptying rate. Overtaking is the salient observable. In the initial racing tests, head starts insure that any changes in starting conditions are 'pushed' against the opportunity for overtaking. Rather than organize the races with a fair start, George fashions the salience of overtaking into a procedure for testing the performance of the 'faster' bottle. One may explain that since George is working along in the first tests, head starts are necessary. However, George always starts the bottle, which won the first test race, second. The bottle that won the first race, filled with blue colored water, serves as a control or threshold against which to measure championship quality tornado tubes. When the contest racing begins, head starts are sought as a strategy for winning rather than testing. George displays two propensities that work together in the episode described here-- strong attention to the dynamics of overtaking and to social competition.

When Mrs. Roos observes the racing, she suggests that the clock be used to compare the performance of the tornado tubes when the amount of initial 'jiggling' is varied. Mrs. Roos' proposes an experimental procedure whose ostensible outcome is the discovery of the effect of jiggling on emptying rate. George has already accomplished a series of procedures comparing two devices in order to fashion his own into a 'winning' tornado tube. Mrs. Roos suggests using the standard analog device for quantifying time. George uses an intrinsic measure of time in performance of the tornado tube he first notices because of its surprising ability to overtake his own device. We may be reminded at this point of Hein's description of the difference between adults' and children's orientations to both phenomena and investigations of phenomena.

The Billiard Ball Tape

The second episode to be considered in the context of racing differs from the first in several ways. The students in the Billiard Ball Tape were students in my seventh grade science class and were 12 or 13 years old. The tape itself was made as students presented their findings after a unit on motion. Thus the Tornado Tubes Tape captured children in the midst of investigation, and the Billiard Ball Tape recorded children's public expression of their ideas and findings from an investigation. The summer science camp only lasted two weeks. The unit on motion took nearly three weeks of 45-minute daily periods. A number of student groups were recorded during the motion study and presentations, and any one of the episodes holds data worth examining. One particular tape is based on a seventh grade students' interviews and observations of other students engaged in investigations of the billiard balls on the inclined plane. The particular tape selected for discussion here came to my notice the moment it was recorded. In the introduction to a demonstration of methods, one of the students explains, "You don't need to time it, you just need to see it." The moment this student (named Manny in the transcript) made his claim, I immediately thought of the Tornado Tube Tape. The selection has elements of serendipity and bias. My own experience as a researcher affected my perceptions as a teacher and consequently the boundary between teacher and practitioner is blurred in this study of racing.

The study of motion for the seventh grade science classes began with a series of staged races. The rationale was to provide vivid, direct experience with controlled motion events. This strategy has been used by some workers through computer based micro-worlds. We discussed, developed, and implemented measurement protocols for motion. A straight track of 50 meters was laid out on an unused driveway on the school campus. Students took roles as runners, starters, timers, and recorders. Timers were positioned at stations spaced at ten meter intervals from the start and used standard, handheld digital stopwatches. Runners were instructed to move along the track in a particular manner by me. The kind of event was not revealed to the timers before hand. One runner began walking before the starting line and continued at a constant speed from the starting line to the finish. A second runner produced constant speed data in the same manner for a run. A third sprinted across the starting line and slowed down steadily and crossed the finish at a slow walk. The fourth began at rest at the start and walked slowly the first ten meters, picked up speed steadily, and crossed the finish at a sprint. The fifth involved a standard 50-meter sprint from rest with two runners. And the sixth event involved a 'tortoise and hare' race where both runners started from rest and crossed the finish simultaneously. The tortoise walked at a slow, constant speed and the hare ran forward and backward, sat down, ran circles around the tortoise, and jumped up and down. After times were recorded for each event along with anecdotal descriptions, the class constructed distance versus time graphs. The graphing exercise involved instruction, practice, and discussion. The hope was that the abstraction of graphical representation would be grounded in common, student-scale events.

The discussion of the data involved recognition in the graphical patterns of faster, slower, constant speed, changing speed, getting faster, getting slower, and rest. The concept of average speed was discussed in terms of the graph and the arithmetical algorithm. The tortoise and hare race was used explicitly to point out the 'meaning' of average speed.

The next activity involved walking to a nearby trainstop (rapid transit) and timing the trains leaving the station. The track was above ground and supporting pillars provided landmarks against which to judge the train's progress. A procedure analogous to that used for the staged races was developed and implemented. Timers were positioned along the road parallel to the track with clear views of the student giving the starting signal and of the designated track pillar for marking the train's time at the particular place. A team of students measured the distance in meters along the track to each observation point. Once data were obtained, students graphed the measures in close analogy to the staged races and answered qualitative and quantitative questions about the train's motion.

For the final activity we used pairs of straight steel pipes held together by small strap-welds. The pipes were four meters long and relatively straight and acceptably smooth. Each group of four students (self-selected) had the use of one set of pipes, stopwatches, rulers, and two different sized cue balls. The entire class received a common assignment that they should find out 'how the billiard ball moves down the inclined plane?' The meaning of the question was discussed and defined. Students were to decide if the ball moved with a constant or changing speed. The problem recalls Galileo's investigation of acceleration. Students were asked to determine what value they could assign for the average speed of the ball for the four-meter trip. They were specifically asked to compare the times for the ball to roll half a specified distance to the time it took the ball to roll the whole distance. And they were also to determine the distance the ball had rolled when half the time for a whole trip had passed. Students were given the choice to choose an investigative question of their own to complete their inquiry into the ball rolling down an inclined plane.

For the open-choice question children examined the effect on the parameters of descent of changing the angle of inclination or of the size of the ball. Some groups tried to find the point at which acceleration seemed to decline-- these students felt 'terminal velocity' was inevitable. One group tried to develop a measure of impact and then wanted to compare degree of impact with angle of inclination of the ramp. As might be expected for middle schoolers, the abilities to gather data, to analyze measurements, and to develop interpretations ranged from frustrated and confused to excited and inspired. Groups had six to seven class periods of 45 minutes to carry out both the common and open investigations and to prepare their presentations. Students were accustomed to a presentation format that involved demonstration, explication, presentation of data, and questioning from other students and from me.

Manny, Bill, Joe, and Wally began their presentation by demonstrating what they felt was a crucial observation about the way the two different billiard balls rolled down the inclined plane. The initial statement by Manny reveals the great salience the gap between the balls holds for his observations and conceptions. In a sense he judges relative speeds with respect to a widening or shrinking distance between the balls. Because one ball must be placed in front of the other, a head start is embedded in the procedure. It never occurred to the group to race the balls with each other on parallel tracks. In their first attempt to demonstrate the gap phenomenon, they tried to release the balls simultaneously but without touching at the top of the ramp. The presentation begins:

Teacher: OK, would you tell us what you doing there?
Manny: We're gonna put the heavier ball in front of the lighter ball and the space between the lighter and the heavy ball is about three to four centimeters and as the two balls go down the ramp, it will get larger -- the space between the two balls.
Bill: OK, ready (Wally and Bill each release a ball).
Manny: You saw it almost like doubles between the balls.
Student: How heavy are the balls?
Manny: 160 and 140. (Pause) Now we'll do it the other way around. The bigger ball behind the smaller ball. The bigger ball should catch up and should touch the small ball.
Bill: Ready, set (each releases a ball.)
Manny: It should have.
Teacher: Explain why it should.
Manny: Well, when we--because the bigger ball had more mass and more mass down a ramp usually (adds to the speed?) and we did it three or four times before-- and they like touch around here.
Joe: It starts out slower and the bigger ball starts slower but it goes faster near the end.
Manny: And then it like touches at the end.
Teacher: What happened just then?
Manny: Maybe they started too far apart. So if we start closer, if we start slightly closer, it should catch up. (to Joe) Did they catch up?
Students in class: No. (mumbling)

At this point the boys' presentation becomes confusing. Their demonstration produces an infelicitous result and the data they try to present is not fully developed. We decide to stop the presentations at that point and remind groups what points need to be covered. The presentations would resume the next day. In essence, extra time was provided for the preparation of final details. As I was concerned with students feeling confident and in expressing their ideas clearly, I felt the group had gotten off to a disappointing start when their crucial demonstration did not produce the result they predicted. I was alerted, however, to Manny's noticing of the gap and suspected his attention might be related to what I associated with a 'racing schema.'

The next day Joe begins the presentation and targets the technique they used to release the balls as responsible for the result they had not predicted. Interestingly they run the balls separately and time their descents down the 4-meter ramp at the halfway point and at the end. Although they speak of (average) speeds, they only use the measured times.

Joe: We're doing our demonstration again, about the same like how the big ball can catch up to the little ball if you use them at the same time.
Teacher: Would you guys speak up?
Joe: And on Wednesday, I think that there was some kind of problem with the release of the ball because the little ball was going ahead too far.
Manny: Um. We'll do the demo, demonstration again. The big ball first, then the small ball, and the big ball behind the small ball, and the small ball behind-- the big ball in front of the small ball.
Bill: First we're going to do the big ball. OK, ready, go.
Joe: 2.74 (at 2 meters).
Manny: 4.09 (at 4 meters).
Teacher: Will you write it up there so we can see it?
Manny: Pardon.
Teacher: Write the times up.
(brief discussion about lights and overhead projector)
Manny: (Writing times from 2 stopwatches on the board.)
Teacher: That's what you got just now?
Group: Yeah.
Bill: OK, now we're going to use the small ball and see how the times differ.
Bill (inaudible to Manny): 2.8.
Manny: 3.94.
Student: Was that the smaller ball?
Manny: Yes, the smaller ball. (Writing times on board.)
Teacher: Well, that's pretty interesting.
Manny: The big ball went faster for the beginning half and it ended up slower than the 140 gram ball which was slower in the first half and faster in the second half. Now we'll do the small ball behind the big ball. There's no need. You don't need to time it, you just need to see it.
Joe: We're showing that the big ball can go faster because the spacing between them got bigger when they went down.
Manny: Now we'll see if the big ball can catch up to the little ball. But with the same distance in between. (balls roll) Did you notice that the big ball caught up with the little ball?
Joe: And then on Wednesday it didn't really go right. I think something was wrong with the way we released it because I think the release-- it makes a difference because the big ball speeds up when it goes down further and the little ball starts out faster.

Manny repeats the idea he expressed the day before that observations of the gap are more significant than times. When Joe and Manny do discuss the times, they regard them as ordering quantities only. No consideration is given to measurement error and the degree of precision in the measured times. The gaps do develop today as the boys suggest, and they treat the times as if winners are determined within the fractions of a second. The explanation that the different sized balls accelerate differently is consistent with the times they do obtain. Both attention to the changing size of the gap and to the ordering function of the times support the focus on racing as the approach Manny uses to discuss the motion of the billiard balls.

Student: Why do you think the 160 gram ball went faster? What do you think caused that?
Joe: Well, I think. You can't always get the times exactly right. Maybe you messed up the time er

maybe something just changed or something.
Manny: I think the big ball should go faster. I think just the weight-- the size actually doesn't make a difference as to the weight of the ball. The smaller ball could have been smaller in size but heavier in weight, but in this case the small ball was smaller in size and smaller in weight. And the big ball was heavier and larger in size.
Teacher: So how do you know it's not the size?
Joe: We don't know. It could be the weight or it could be the size.
Manny: Or it could be both also.

Manny and Joe take the lead in discussing their data and demonstrations. From the beginning they expected the heavier/larger ball to go faster. During the first attempt to make the presentation, Manny suggested that more mass adds to speed down a ramp. The boys do make distinctions between size and weight leading one to suspect they have some concept of density. They also acknowledge the limit of their evidence, but Manny consistently asserts that he thinks weight matters.

When the group presents their graphical data, they engage in discussion of the shapes and slopes of the graph lines. Manny superimposes the transparencies of the distance versus time graphs of the two different balls. Interestingly he oscillates between judging the speed curves as different and the same. He grapples with reconciling his expectations with the data his group has gathered and presented.

Wally: (using the overhead projector) This is the graph again. This is the average speed line and as you can see at the fourth meter the time for the dot is (inaudible) and that the balls accelerate down the ramp, they got faster. And uh, the second dot is on the curve that we made but the other three.
Manny: Well, the first dot is kind of on the right hand side of the curve and the 3rd meter dot is kind of on the left hand side. That says that the ball doesn't really average out into a constant speed by the 4th meter. Maybe if we continued to like10 or 11 meters, it might go at a constant speed. But we have to try that, we're not really sure what would happen. And the 140 gram ball. We'll put the two graphs on top of each other to show the difference of the balls. (superimposes graphs) You see. (Aside) Which one's which?
Wally: (gets up to point) You see this one, the line right there is 140 and the bottom one below it is the 160.
Manny: So this kind of shows that there's not much difference in the speeds. Just that if you actually put it on the graph you can actually see the difference. There's not much difference between the speeds.
Teacher: So which one is which?
Manny: This one here, the very first one is 140 and this one here is 160.
Teacher: So do they cross?
Bill: No, parallel.
Teacher: So what does the graph tell us about this event?
Manny: It says that, I don't know, the average speeds are almost the same as well. And the curves? The curve's like it's the same curve but it's just different.
Teacher: Does that fit with your expectations?
Joe: Not really. Because the first curve here seems to be going more like up there. And the

second one is going up like that way more. So from the graph it shows that the 160 isn't going as fast because it's going more to the right.

Each of the boys who expresses a thought seems to assume that the balls must have different trips down the inclined plane. That neither the data nor the demonstrations provide clear evidence that one ball travels consistently and significantly faster than the other leads them to discuss procedures and possible causes and to reformulate their predictions. They do not, however, consider the possibility that the balls have very similar trips. The racing assumption predominates like the cultural bias Hein described in his article on a similar experience with children exploring similar phenomena.

The boys express their views with some sophistication. They consider the implications of their theory-like notions and recognize when the data do not match.

Teacher: This is interesting because you have shown us a couple of things that make it look one way and a couple of things that make it look another way. Am I right in that or am I confused?
Joe: That's right.
Teacher: What do you think about all that?
Manny: Bill just said that the 160 ball goes up and goes further, is that what you said?
Bill: Yeah, the 160 ball it starts off faster than the 140 and further down the ramp the 160 ball goes the slower it slows down, but the 140 ball picks up more speed.
Teacher: Does that fit the graph?
Bill and others: Yeah.
Teacher: What about that overtaking or closing in demo that you showed us? How does that fit in?
Manny: What my expectation was that the big ball would probably be faster down the ramp.
Teacher: Uh huh.
Manny: But the timings and the graph say that the small ball picks up faster at the last half. And I thought that the larger ball would be faster all the way. But it looks like the small ball was faster from the half to the end.
Teacher: Have you thought any about that? I mean how do you explain that?
Manny: I'm not really sure. I think if you actually make the ramp, say, doubled, 8 meters.
Teacher: Length, yeah.
Manny: You can see that if, you can actually see the smaller ball and the bigger ball--which one's faster. Because if you have a longer length you can actually have more predictions of what the timing will be.
Teacher: So it can kind of amplify or spread out any difference?
Manny: Maybe then we could see if the timings---
Teacher: So what do you think would happen if we had the same angle as that but doubled the length of the ramp, what do you think would happen?
Manny: The smaller ball pick up--putting the small ball in front of the bigger one?
Teacher: Yeah.
Manny: As soon as it'll catch up with the big one, I think the small ball might pick up speed. And it might separate at the end.

Manny persists somewhat in his idea that the bigger ball should be faster even though he admits that the graphs do not support such an idea. He imagines that a better test would involve a longer ramp. His thought-experiment does not have enough distance to develop in the four-meter ramp. Manny's interpretations and predictions do become more fragmented as he faces the data he and his partners have collected.

While Manny raises questions about the too short ramp, Joe tries to develop an ad hoc mechanical explanation for how a gap might increase with the small ball in front when the two balls are rolled down the same plane. The big ball actually goes faster but it knocks the small ball and gives it a kick to jump ahead. The explanation is a fascinating example of 'saving the phenomena' while 'conserving the theory.' The underlying assumption remains that there is a race with one winner.

Joe: Well, if we go like this (takes two balls and sets them on the ramp about .3 meter apart), the big ball catches up, it's going to bump the small ball and this'll go real faster.
Teacher: OK, now, Joe you start at the beginning and demonstrate with the two balls going down the ramp what you think is happening. That sounds kind of interesting.
Joe: I think if the big ball catches up.
Teacher: OK, if it catches up. Do you think it does catch up or not?
Joe: I think it will. It'll hit this one and if it hits it--
Teacher: When would you expect it to hit?
Joe: On the end.
(Manny and Joe release balls. Manny walks beside.)
Manny: It caught up right there. You had to be close enough to see it.
Teacher: OK, give us a play by play, Manny. Do it again. And give us a play by play as they roll down--what's happening? On the other side, yeah, and maybe do both situations, and then we'll see if there are any questions. This is very interesting.
Manny: (ball are released) (Manny points) It caught up there. It caught up along.
Teacher: Did they bang, did they click?
Manny: Yeah, they clicked. It's actually that they are--the small ball is like a millimeter away from--after it hits--And the small ball spreads out about a millimeter or two.

Manny asserts early in the presentation that seeing is sufficient for confirming predictions. And when effects are small, he explains, "You had to be close enough to see it." As the presentation ends, Joe is asked to make a summary statement. He says, "I think that we have mixed opinions, but we both agree that when you do the two balls, to test them, the little ball put it in back, then the distance between them will increase. But if you put the little ball in front then the big ball will usually catch up." Both boys are facile enough with graphical data, with measurement, and with derived quantities like density and speed. They can both speak understandably if qualitatively about changing quantities. They can perform live demonstrations and can imagine thought experiments. They can acknowledge uncertainty as they assert a conceptual conviction.

But data is interpreted almost totally in terms of the order of a race. The significance of slight differences in measurement is seen as real race order difference. The values the boys got during the demonstration are the same as those obtained by watching the video and timing the event with a stopwatch. Their measurements are as good as any. They can make the measurements;

they do make the measurements; they can present the measurements graphically; they can perform calculations with the measurements. But for Manny, the approach remains, perhaps like a cultural truth, "You don't need to time it, you just need to see it." And what is to be seen is the outcome of the event through the perspective of a race.

Tornado Tubes and Billiard Balls

For me it is compelling to think that the children's focus on overtaking and head starts in the Tornado Tubes Tape and on changing gaps and differing speeds in the Billiard Balls Tape arises from the same source. The data presented here do not verify the similarities, but there are corroborative reflections in studies of children's interpretations of motion. (Piaget, 1970; Piaget and Garcia, 1989) In spite of the differences between the taped episodes presented here-- the difference in ages of the students, the differences between the educational settings, the differences in the relationship between the author and the children, the differences between the phenomena under investigation, and so on-- racing and racing ideas are clearly present in both and these racing ideas are applied vividly and held strongly by the children, who appear in both tapes.

Once racing is seen as a predominate mode, more questions arise. Do children notice the race because of a kind of innate 'search image' or 'noticing grammar?' Do they arrange races because of a developmental organizing scheme that is initially tied to perceptual salience? Do races result in a conflation of tests and contests where physical and social interests meet? Are races and the mental apparatus for noticing races something deep in human nature-- serving as orienting and organizing systems for both the physical and social worlds?

The implications of racing for teaching science

While it is fascinating to wonder about the origins of the racing schema in children, a teacher wonders what he or she ought to do. What should teachers do when racing appears in science investigations: stage-manage a transition, do nothing, build upon aspects of the race? Are there beneficial consequences to the full-fledged adoption of racing as an organizing principle for curriculum? Would science-for-all-children be enhanced if racing were discouraged or if transitions from racing were encouraged? Does the appearance of racing ideas and approaches in children's science relate to other observed predilections like engineering and design modes (Schauble, Klopfer, and Raghavan, 1991)?

In the introduction to Scientific American's special issue on Extreme Engineering (1999), the editors write:

What drives us to reshape our world-to build taller buildings, faster vehicles, smaller computer chips? Is it something innate that pushes us past the limits, helping us to redefine the boundaries of what is possible? The history of civilization is filled with the challenge, the daring-and at times the sheer audacity-of innovative engineering, with each advance enabling countless others. This proud lineage is a testament to our imagination and ingenuity, reaffirming the very qualities that make us human. Here we present our choices for the most noteworthy human achievements. (p. 8)

I have thought (without rigorous evidence) that the racing schema could be conflated and extrapolated to a fascination with limits, boundaries, and thresholds and at one time organized much of my own activity-oriented, inquiry-based science teaching on such an organizing principle (Frazier, 1993). Teaching science along such principles can be engaging for students, but may fall short for those who require the inculcation of standard science. Using the race as a paradigm in school science may be exactly the situation Hein described as "going native."

In the Tornado Tubes Tape, a teacher initially proposes racing, but Mrs. Roos seems troubled by the racing she observes later. When I have presented the episode to both practicing and preservice teachers, both groups seem to value the way George encounters variables from his own perspective but not the racing that occurs between the boys toward the end of the episode. In my own work with children in the study of motion, I have marveled at the success of some in acquiring skills necessary for applying standard conceptions while employing a different approach toward appropriate phenomena when given the choice. Manny, in fact, explicitly denies the importance of so-called scientific observations when investigating motion according to his own perspective.

Can the cultural metaphor offer inspiration for bridging an impasse? A sympathetic interpretation assumes that the culture of children's science has some worth. Perhaps it is possible to use racing as a starting point.

I would like to conclude with an inspiring idea from a personal inquiry project conducted by a preservice teacher in my Physics for Teachers course. Kelly van Winkle embarked on a study of the motion of balls rolling down a hill. Part of the inquiry involved research into children's ideas. She worked with a middle schooler gathering times for the descent of a variety of balls down an incline. She expected a number of factors to affect the course of each ball's trip. She also interviewed her little brother using his favorite toy cars. The little boy's idea of motion predictably focused on deciding which car was faster. Several conceptions of the causes of speed were offered: Weight, kind of car, and size. Van Winkle developed a lesson plan that involved a predictive sorting of cars into those imagined to be 'fast' and those imagined to be 'slow.' Pairs of cars were then to be selected from the presumed fast and slow groups to be raced on inclined planes. In this lesson, children's ideas were used to classify and make predictions. A racing format was used to test the children's ideas. In the process of incorporating children's ideas about motion and in using a racing test, it became possible to examine conceptions of what affects speed.

This example combines "going native" with practices valued in standard science. Children's ideas about faster and slower are treated as mini-hypotheses that can generate predictions about winners and losers of imagined races. The race is used explicitly as a test of the children's presumed predictions. Races and contests can have much in common with experimental tests. Issues of fairness arise when variables are identified and controlled. Observables are defined when methods of scoring are carefully described. Developing techniques for making fair starts and observing finishes can involve students in decisions critical for interpreting experimental results. When children's predictions do not prove correct, techniques can be refined; initial conceptions can be revisited. Finer descriptions of the motion can be effected. The need to learn and use measurement arises from the investigation itself rather than as an isolated part of externally imposed standards. Better for Manny to find timing important because it allows him to look more closely at the world and at his ideas than because the teacher admonishes him to join the culture of adult science.

Enthusiastically embracing children's science may lead to a happy, if arranged, marriage with standard science. Certainly, in such an approach it becomes incumbent on the teacher to know and respect children's science as well as standard science. But even when teachers, researchers, and curriculum developers conceptualize students' encounters with phenomena as different from those of adult scientists, they may still have no clear direction for action. As indicated in the tornado tubes episode, the boys' racing does not necessarily lead toward their understanding the standard explanations of water swirling and falling into the closed bottle. It is also possible for someone who accepts the predilection of racing among children's ideas to regard such ideas as challenges that should be redirected, replaced, or eradicated. There are other possibilities. Examples of cultural hybridization or amalgamation may provide inspiration for taking children's ideas and approaches and fashioning them into practices that are mutually respectable and intelligible in both children's and standard science. Perhaps a new metaphor for a science teacher should be that of a bilingual, bi-cultural ambassador seeking understanding and partnership for mutual benefit.

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