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# Bicycles

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## Introduction

“I hate Math because it’s dumb and boring.” Two years ago I coached a youth soccer team composed of nine and ten year olds. Most of my players used negative statements similar, to the above, to describe their mathematics education. These were ordinary children, playing on a recreation team, who otherwise liked school.

Jacqueline A. Hershey’s article, “How Schools Sabotage a Creative Work Force,” appearing in the July 13, 1987 issue of *Business Week,* reminded me of my old team. Dr. Hershey complains about the methods schools are using to teach math and science to her two children. The inane repetition distressed Dr. Hershey and her children just as it had turned off my team.

Dr. Hershey concludes her article by saying how America can ill afford to produce students that are technically illiterate. I totally subscribe to that view. More and more manufacturing jobs are leaving the United States. The jobs that remain require an increasing amount of technical sophistication. This summer I am working for the Barnes Group, the chief manufacturer of automotive springs in the United States. The office workers must be proficient with personal computers, modems, laser printers and increasingly complex software packages.

John A Dorsey, the current president of the National Council of Teachers of Mathematics, stated that math will play a more important role in future life, in the world of work that is becoming more technological. Math skills are a key to economic security and a chance for advancement.

As a teacher, I see the skills that the work world requires and I want to provide my students with the necessary technical knowledge. Much of our present curriculum lacks the challenge and vitality to do this. James T. Fey, a professor of mathematics at the University of Maryland feels that we spend too much time trying to get students to learn skills that are outdated. The goal is to get students to solve problems. We’ve got to find a way to avoid endless preparation in low-level skills. Technology can help students achieve that goal.

When I was coaching I didn’t want to lose. I did not view a defeat as the end of the world though or tell my players that they were losers I don’t want my students to be losers either. I want to prepare my students to be able to compete successfully. This requires being comfortable with rather than being afraid of math and science.

The other reason why it hurts me to see students not like mathematics is that I'm a math teacher. I enjoy doing math. I want my students to experience the same pleasure, the same feelings of success. Math is a big puzzle waiting to be solved, an exciting cause and effect game.

I would like to clarify one point. When I say that I want my students to be able to get a job, I do not mean that money is the ultimate aim. However, I think you'll feel better about yourself if you are using your skills rather than being unemployed. My mother has said that she's been rich and she's been poor; and that she likes being rich better.

## Getting Started

Well then, how do we improve math and science courses so that students race down the hallways to be on time? Can the United States respond to Toyota like it did to Sputnik? I feel that the students need more hands-on activities. These will prepare the student for more abstract learning in a challenging and motivating manner. However, the increase in supplies will cost money. The classroom may also become noisy and appear unstructured.

Intellectual development for all of us is based on stages of growth in our ability to think and reason. Jean Piaget, a Swiss psychologist, did extensive research on an individual's mental abilities and intellectual growth. He devised a theory that intellectual development is a four stage process; sensory-motor, preoperational, concrete operational and formal operational periods.

According to Piaget, there is an age range associated with each period. However, the starting or ending of a stage varies according to the child's environment, abilities and socioeconomic position.

The concrete operational period involves the child during the approximate ages of seven to eleven. During this time period, children are exposed to the fundamentals of mathematics. Although the child's thinking in this stage is becoming more logical and systematic, it is still limited to what he has experienced. When a child encounters a new situation, he compares it to physical situation that he has already experienced. He is comparing and learning from experience but not yet internalizing.

As the child grows older, he learns the ideas of conservation of number, area, weight and volume. If he develops a process to group and to organize information, then the child is ready to learn abstract concepts. The child s progress from the stage of concrete experiences to the stage of formal operational thought depends upon the kinds of experiences the child has had.

In the formal operational period, a child learns to try various possibilities to solve a problem. He learns cause and effect relationships; dropping things that don't work and keeping things that help him discover the cause of events. A child learns to plan moves and predict likely outcomes.

In the United States today, the teaching of math seems to be stuck on the concrete operational stage based purely on the memorization of facts. I am interested in approaching the teaching of math on the concrete operational stage, but by the child experiencing concepts of math and then applying them to daily experiences. As the child draws on his experiences, he then progresses into the formal operational stage of thinking. In this period, math should become fun or at least interesting.

## Unit Objectives

The primary objective of this unit is to demonstrate, through a collection of applications, how you can effectively use bicycles to teach mathematics and science. The unit emphasizes easy to do experiments. The appendix discusses approximate numbers and significant digits.

In teaching, I try to actively involve the student. Last year, my Yale-New Haven Teachers Institute seminar leader Dr. William Kessen, Professor of Psychology and Pediatrics, stressed using data that was drawn from the student's life experiences. All my students can ride a bicycle. My students and I are involved with a practical concrete object. Hopefully, the team attitude will produce a "Yes, I can" in learning the physics and mathematics of a bicycle; that the success in performing on a bicycle can be replicated in the classroom.

If you teach mathematics or science, in either junior high school or high school , you can use this unit. This unit contains applications to program in a computer class. This unit would also be helpful to anyone who is preparing for the Armed Services Vocational Aptitude Battery Test, as that test has sections on mathematics, general science and basic mechanics.

## Section Outline

The unit begins with a discussion of circles. It covers the parts of a circle, related lines, circumference, and the distance a rolling wheel travels. Students use experiments to find Pi, circumference and distance. This section would be useful to a junior high math teacher introducing circles or to a high school teacher who has students that don't understand circles. I have used these experiments and I have found that when the student performed the experiments, he learned the concepts.

The next section introduces motion. It gives easy to understand definitions and descriptions of distance, speed, velocity, acceleration, and friction. The motion experiments are described later in the paper. This section is geared to a junior high science class or to a freshman physical science class.

In the next section, motion is treated more mathematically. The rate of change of a function is treated in as graphical an approach as possible. This section is excellent for any math class which teaches coordinate axis or graphing. It could also be used in a precalculus or calculus class to physically show the concepts of differentiation and integration. The number manipulations and graphs are also excellent exercises for a spreadsheet class. I try to show my students that spreadsheets are tools that they can use to solve a variety of problems.

Simple machines are then explored. There are six simple machines: the lever, pulley, wheel and axle, inclined plane, wedge, and screw. I have tried to stress that although machines decrease effort, they do not decrease work. It is impossible to get more work out of a machine than you put into it. This section is designed for a junior high science class or for a freshman physical science class.

## Circles

A circle is a set of points in a plane that are equidistant from a fixed point called the center. A radius of a circle is a line segment drawn from the center of the circle to any point on the circle. A chord of a circle is a line segment whose endpoints are on the circle. A diameter of a circle is a chord that contains the center of the circle. So far, there is no problem in teaching definitions involving circles. The students know what a circle looks like; they started seeing them on Sesame Street.

Tangents and secants are a little trickier. A tangent to a circle is a line in the plane of the circle which intersects the circle at one and only one point. The point at which the tangent intersects the circle is called the "point of tangency." A few years ago, one of the rubber companies had a commercial which contained the lyrics, "where the rubber meets the road." I use this to teach that a tangent only touches the circle at one point. I pick a light student and say how if he got on a ten speed the tire would only touch the ground at one point, especially if we filled the tire to a high pressure. But, if I got on the bike that the tire would flatten out and touch in many places. That is, if it didn't burst.

A secant is a line which intersects a circle in two points. A simple enough definition, but if you start drawing the secant outside the circle and stop drawing the secant inside the circle and ask the students, "What kind of line is it?" They will respond, "A tangent." I then point out that a line has no endpoints, so that if we continued the secant that it would come out the other side of the circle. And besides, where does the rubber meet the road?

The circumference of a circle is the length of the circle expressed in linear units. I mention how "circum" is Latin for "around", so circumference means the distance around a circle. So far, there are no problems. The textbook then moves to the formula for circumference. I mention "pi" and I may as well be speaking Greek. To quote Piaget, we have gone past concrete knowledge into abstractions.

Pi is the ratio of the circumference of a circle to the length of its diameter no matter what the size of the circle. Bring in the bicycle and other wheels and have the students measure them. Then compare the ratios. The first time I did this I did not have a measuring tape so I used lengths of yarn. Guess what? Yarn stretches. Our results were a little off. However, the students have now physically met pi. When they encounter pi in the formula for circumference, they will not be overwhelmed by the symbol.

My students have found problems like, "How far will a wheel with a five foot diameter travel in two revolutions?" very difficult. They seem to have difficulty translating spinning around to a linear distance. Again, before trying to solve the problem on paper, let's use the bicycle. Wrap a piece of tape around the tire to mark a starting position. You could also use the valve stem as a position marker. Start with the tape on the ground and roll the tire one complete revolution. Now have someone measure the circumference. The two numbers should be the same. Once the student sees the relationship between the circumference and one revolution, you are now ready to roll the tire more than one revolution. Have the student make a chart with multiples of the circumference and compare the computations with the measured distances.

## Motion

Motion means movement from one place to another. When you move from one place to another, you cover a distance. You record the motion of an object by measuring the distance it traveled.

Speed is the distance travelled by an object in a unit of time, or said another way, speed is the rate at which an object covers a given distance. Speed is given by the formula:

**Speed— distance / time**

Although the terms speed and velocity are used interchangeably in everyday speech, they have different meanings. Speed is a scalar. Since speed is a scalar, it describes magnitude only. Speed tells us nothing about the direction in which the object is moving. Velocity is a vector. Because velocity is a vector, it measures speed and direction. Our equation for speed can be rewritten for average velocity:

**Average velocity = distance / time**

I used this equation extensively. My class had measured a course of one hundred twenty yards in increments of thirty yards. In order to find the average velocities, we took the yard distance, multiplied it by 3 to change it into feet, and divided the product by the total elapsed time. These calculations are presented in the two page spreadsheet "David Coasting Down a Slight Incline" which is located at the end of the unit.

We then plotted these points and connected them using a French curve. Each drawing took approximately an hour. The graphs that are presented, again found at the end of the unit, are done with straight lines on graphs produced from Lotus 1-2-3. I have submitted these graphs because they are much more legible.

The results are what we would have expected. The average velocity increases rapidly in the first twenty yards. It continues to increase but at a slightly slower rate over the next forty yards. At this point, the average velocity approaches a limiting value. The graphs have points at the ten and twenty yard line because I redid the experiment with my wife, my son and my son's friend David. I had wanted to see how the slopes started out in more detail at t = 0.

I used the term average velocity because in most instances an object does not travel at a constant velocity. If you ask a student to describe his ride to school, he will tell you about slowing down for traffic lights and speeding up to pass cars. Thus, we arrive at an average velocity. I also mention average velocity to get the student to realize that his velocity can increase or decrease. This leads into acceleration.

**Acceleration is any change in velocity. Acceleration is given by the formula:**

Acceleration = change in velocity / time required for change Acceleration is measured in units of distance/time/time, such as miles per hour per minute or feet per second per second. We have discussed how a moving body has a velocity and can have an acceleration. Therefore, change in velocity is computed by subtracting the initial velocity from the final velocity.

Finding the acceleration was a little more involved. I first used the average velocities, but the results didn't look right. Also, average velocity doesn't seem to fit right in the equation. So, we went back and found the instantaneous velocities at each yard marker. We did this using the formula:

**Instantaneous Velocity = (Change in Distance)/(Change in Time)**

These calculations were fairly straight forward. We went back to our recorded values, found the differences and then the quotients. The results still didn't look right; I had again forgotten to multiply by the three to change the yards to feet.

Now we were ready to find the acceleration. We took the instantaneous velocity and divided it by the change in time. The overall results were good. The acceleration starts off slowly, quickly hits a maximum, and then decreases towards zero as long as the rider is maintaining his velocity. If the rider slows down, a negative acceleration is produced.

We spent two class periods collecting data for velocity and acceleration. Again, I feel that since it was the individual's own times, the concepts were grasped easier. An account of the class actually performing the experiments is described later in the paper.

Friction is the force that opposes or slows down the motion of a body. Otherwise, by Newton's first law, you would be able to coast on your bicycle forever.

In bicycling, air is both your enemy and your friend. It's your friend because it is your main method of cooling. When a bicycle is equipped with fairings, the rider quickly can overheat. It's your enemy because it is the air resistance that slows you down.

The coasting experiment shows the effects of air resistance quite vividly. When a person rides in a normal manner, he is sitting upright and his body offers a lot a surface area. This is a limiting position. To counter this, ten-speeds have their handlebars curled downward so that the rider can pedal in a streamline position. In this position the body is compact and offers less resistance.

New studies are now showing that the streamline position can be improved upon. When a rider is in the streamline position, his elbows are flexed out producing a "parachute" effect. New handlebars have been designed so that now the rider is in a tucked position like a downhill skier. In our experiment, I had the riders place their hands as close together as possible on the handlebars.

The results were convincing for the narrow position. It had the fastest velocity, followed by the streamline and then by the normal position. To dramatize the effects of air resistance, I had the riders coast wearing my winter parka. These times were slower.

## Rate of Change of a Function

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Calculus is the mathematics of change and motion. Calculus is a branch of mathematics which provides methods for solving two large classes of problems. The first of these is differential calculus. It involves finding the rate at which a variable quantity is changing. In our case, we will start with a person on a bicycle at a starting point. We will have timers set up at specified distances. By measuring the change in distance with respect to the change in time, we can determine how fast the bicycle is traveling at any instant.

The second branch of calculus is integral calculus. This branch deals with finding a function when its rate of change is known. In our case, we will start with the graphs for velocity versus time. We will take the area under the curve at specified time intervals. This area should be the distance the rider has traveled.

In this section, I hope to give a person a feel for what the derivative and integral are. I will do this by first plotting points of Kasey pedaling. I will then connect the points. This graph should be a curve. However, as noted in the previous section, the submitted graphs will be done with straight lines. This is not all that bad because in Calculus, you assume that as the interval becomes smaller and smaller that the graph approximates the straight line segment in each interval. I will then draw tangents to the distance versus time graph. I will show how the slope of the tangents is the velocity at the respective points. I will then take the velocity versus time graph and find the area under the curve. I will show how this area is the distance that the rider has traveled. I will not present algorithms to find the derivative or integral.

The section starts with coordinates. The basic idea of analytic geometry is the establishment of a one-to-one correspondence between a pair of numbers and the points on a plane. Some students have difficulty with which coordinate is presented first. I tell them that it is alphabetical order; the x-coordinate is presented first.

Next, we will discuss the slope of a straight line, where slope is given by the change in y-direction divided by the change in the x-direction. In finding the slope of graphs in a mathematics book, I tell my students to start at a point which is on the grid of x and y values. Let’s stay away from fractions. I then tell them to walk forward. It is important to move in the positive direction since this is then one less negative number to worry about. When you hit the next intersection, look up or down the y-axis and see if the graph goes through an intersection. If it does, count how many blocks away the graph is. This is why it is important to move positively along the x-axis, if you move up to meet the graph, you have a positive slope; if you move down, you have a negative slope.

Unfortunately, my graph of the tangents to the distance versus velocity didn’t work out as neatly as a textbook example. Then I noticed something. If I continued the tangent so that it crossed the x-axis, I only had one unknown to estimate. I drew the tangent at a known point; that’s one coordinate pair known. When I cross the x-axis, the y-value is known; it’s zero. That only leaves one x-value to find. This technique worked fine. We will then proceed to the equation for a straight line. We will start with the slope intercept method: $y = mx + b$, where m is the slope and b is the y-intercept. From there we will go to a more general equation $Ax + By + C = O$.

In an advanced class, I would then move to functions. A function is a set of ordered pairs of numbers (x,y) such that to each value of the first variable (x) there corresponds a unique value of the second variable (y). We will then graph the functions.

We now go from the slope of a straight line to the slope of a curve. We can show how if we make the intervals small enough, a curve can be approximated by a set of straight lines. This leads to finding the derivative of a function. By the derivative we mean the slope of the tangent to the curve at a particular point.

I drew five tangent lines to the distance versus time graph. Looking at the graph, the slopes from left to right are 10.7, 17.1, 21.0, 30.5 and 32.1. This matches up to computed velocities of 8.5, 14.0, 22.7, 29.4 and 30.5. So, we’re in the ball park. From these results I was able to show how the slope of the line increases as the velocity increases. Also, how when a state of constant velocity is reached, the lines are parallel.

Although it is not in the scope of this paper, I did a regression analysis on my observed points. I used the Data Regression Menu found in Lotus 1-2-3. This command is straight forward and simple. You do not have to have any knowledge of degrees of freedom or standard error of coefficients. You just plug in the numbers. Using a cubic regression, this method gave me velocities of 9.2, 16.0, 20.2, 28.4, 32.5 and 30.7. I liked this curve fitting method better, but I didn't want to confuse my students. After all, I had been breaking it on them to make sure that their numbers were exact.

To show integration, I took the graph of instantaneous velocity versus time and drew lines parallel to the y-axis through the given points. I then used the trapezoid rule for approximation of the area under a curve. The formula for area of a trapezoid is:

**Area = 1/2 x (basel + base2) x height**

Our results were extremely accurate once the constant velocity state was reached. For our other values, we should have had smaller intervals. However, they were close enough for a Friday in May demonstration.

We could have gone on with the derivative of the velocity to find acceleration. We didn't because, as noted, I wanted to have more measurements. I still view this section as a success because I was able to graphically show the derivative and the integral.

## Simple Machines

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A bicycle can be thought of as a simple machine. A lever is a rigid body pivoted on a fixed fulcrum. A seesaw is an example of a lever. On a seesaw, if a heavy person is at one end and a lighter person is at the other end, the heavy person can keep the lighter one suspended in the air. But, what happens if the heavier person moves closer to the center? Eventually, a point will be reached where the two people will balance each other. If the heavier person moves still closer, the lighter person can now keep the heavier one up in the air.

Levers use the principle that force times distance of the effort equals force times distance of the resistance. If a person applies a fifty pound force four feet from the fulcrum, he can move a two hundred pound weight which is one foot from the fulcrum.

Force times distance is also the formula for work. Work is the product of the force applied to an object by an outside agent and the distance through which the force acts on the object. It is important to remember distance. The lighter force must move through a greater distance. If you are using a crowbar to move a rock you may move one foot to move the rock one inch. The work remains the same. If the force increases the distance decreases, and vice versa.

A ten speed uses gears, where a gear can be thought of as a spinning lever. A gear is a wheel with projections on it called teeth. On a bicycle, these teeth are on the edge of the wheel. This type of gear is called a spur gear. When you talk about force when you are using gears, you talk about torque. Torque is a force that can produce rotation. Torque is equal to the distance from the point of application of the force to the center of rotation multiplied by the component of force perpendicular to this distance.

On a bicycle, the teeth are connected by the chain. The rider makes the front gears go around, which drives the chain, which turns the rear gears. The rear gears are fixed on the wheel. When the rear gears turn, the wheel turns. It is important to realize how the chain works. A link of chain fits over a tooth in a gear. A movement of one link in the chainwheel causes a movement of one link in the freewheel. With gears if torque increases then speed decreases.

My bicycle has a 40-50 combination of teeth on the chainwheel. Does this mean that I travel fifty inches for every revolution of the pedals? No, it means that one revolution of the pedals causes the chain to move fifty links. The distance I travel depends on how many teeth are on the gear in the back wheel. One of the sprockets on my freewheel has thirteen teeth. One revolution of the crank will turn my rear wheel 3.84 times. Since the diameter of my tires is twenty-seven inches, I will travel 84.78 inches.

## Experiments

This is the real fun part of the course. On a warm Friday afternoon in May, would you rather be in a hot stuffy classroom or would you rather be freewheeling on your ten-speed bicycle in the balmy spring breeze? This past May, Friday was Bicycle Experiment Day for my seventh period Data Entry class. Seventh period had twenty-four students; my classroom had ten working computers at that point in time.

I have stated earlier how I view teaching as a team activity. The students and I arrive at a game plan and try to execute it. Sometimes a team responds well to a different activity. During the week, I was able to push seventh period harder than my other two Data Entry classes. After all, on Friday we weren't going to work, since Friday was Bicycle Experiment Day.

## Week 1

We tried an experiment on our first Friday to see if we could measure how far a bicycle could travel in different gear combinations. We will talk about it next, but first let's look at what they're talking about in a gear table that you find in the rear of many bicycle books. When a book talks about how many inches any particular gear is, the inches refer to the size wheel any particular gear would require if it were straight drive. Many of the old high-wheelers had a fifty-four inch gear. That means that the diameter of the front wheel was fifty-four inches. This made the bike cumbersome and unsafe. How would you find a fifty-four inch gear on my bike? The formula is the product of the number of teeth on the front sprocket divided by the number of teeth on the rear sprocket times twenty-seven inches, where twenty-seven inches is the wheel diameter. So, on my bike with fifty teeth on the front sprocket, I would have twenty-five teeth on my rear sprocket to attain a fifty-four inch gear. This formula is a perfect spreadsheet application. We will be able to generate the table. My kids get excited when they do real work.

Now, let's look back to our first experiment. It was a horror show. This was our first time breaking the traditional classroom setting. We worked in the courtyard outside of the school. The courtyard has cement blocks six feet square. The skepticism of my immediate boss and the principal did not help. They could not understand how being outside with bicycles was related to computers. So the first problem was to assure my students that it was ok to have fun while learning.

We had three bicycles. I had brought in mine, which all the kids laughed at just because it's older than they are, and two students had brought in their bicycles. We only had one tape and it was twelve feet, but we had three yard sticks. We marked off a starting point and then marked off every six feet so that the students would have a line to measure from. I should have marked off every three feet since they were unable to measure backwards.

We broke the class into groups. We had riders, recorders, judges and measurers. We assigned people to their groups after we got outside. I should have done that inside. The courtyard in some places is only twelve feet wide so we only used two bicycles. Mine has stirrups which the rider did not know how to use, so after he smashed one by driving it into the ground, we retired my bike.

For the experiment we asked the rider to pedal two complete revolutions. Because we had not gone over anything beforehand, the riders were trying to stop after two revolutions. This caused them to coast. Our other difficulty was the slippage in the crank. I had wanted two revolutions to minimize initial resistance, but the one bicycle crank seemed to move twenty degrees before the bicycle started to move. The other difficulty was in trying to judge the point where the second revolution ended. In this class two of my students are mothers. They finally became frustrated, took control, and started collecting data. We then told the rider to continue to pedal smoothly and the girls were able to get readings.

At the end of the experiment, we asked the two riders to go all out over the entire course which was about four hundred feet long and the riders were winded. They felt that that distance should be long enough for future experiments where we will time the riders at fixed intervals in different gear combinations.

## Week 2

The next week it rained on Friday. We remained in the classroom and did regular work. However, on Thursday I had taken time from class to organize the class into assigned tasks. The class also helped decide how the procedures would be run. They decided that the starter would drop a soccer flag to start the rider. They felt that it would be too hard to see a light from a far distance.

## Week 3

The next Friday, we were all set. Several students brought in stop watches and I brought in my bicycle. First, the students covered the course in high gear. Most of the students were serious. Ten yards past the end of the course are three vertical pipes which prevent cars from riding in the courtyard. Since most of my students who were pedaling were good riders, I did not think that the pipes presented any danger. No, nobody did ride into them. However, one student skidded for twenty yards to show off how much of my rubber he could leave on the course. Another student was leery of the pipes and coasted the final thirty yards.

Then we switched to low gear. Eric was pumping away. He heard a banging noise, but he was not going to stop. This was a bicycle experiment. My derailleur became caught in the spokes of the wheel. Eric kept pedaling with such force that the derailleur spun around breaking the rear drop out. This makes the rest of the frame worthless. To add insult, when I brought the bicycle to the shop, the man said that in its time my bike was ok but that now it was an old iron clunker. I had failed to heed the advice found in *Zen and the Art of Motorcycle Maintenance* to maintain my bike in excellent condition.

## Week 4

Since I no longer had a bicycle, I thought that the experiments were finished. But, the next week Antoine brought in his bicycle. This time we tried to have the students pedal at a constant rate. I had hoped to have the students listen to a Walkman playing rap music. However, I had forgotten my son's Walkman, so the students tried to pedal at a constant rate. This week there were no tragedies.

I also have four students from the tennis team and they said that they would work with me after school to determine limiting effects on bicycle speed in another set of experiments.

I enjoyed the experiments. My students learned a little about gears. I had asked the students when would they pedal in low gear. I explained that in low gear the rear wheel does not travel very fast. Their response was that you use low gear when you're riding by a street corner that has some pretty girls standing on it. We got around to maybe you might want to use it on hills.

## A Month Later

School is now out. Writing this paper keeps seventh period in my mind. My first memory is Lise. She wanted me to fix her bike. Since I'm not that mechanical and since there doesn't seem to be enough time during the end of the year, I didn't. But what an opportunity I wasted. This could have made the school environment much more real and friendly to her. Since Lise was a class leader, maybe a few other students would have become more interested in school.

This is not to say that the class was bad. A second memory is Maurice. He blossomed into a B student with me this year. I feel that with more usage of bicycles I would have more active involvement from more students. They too would not be afraid to show Maurice's enthusiasm towards school.

A final memory is Anthony, a junior high student I taught in Baltimore. In the early seventies when I started teaching, I had forty students in a class. I didn't think about using bicycles then, but we did play roller derby. I divided the class into teams and we computed decimals and percentages. Well I can't skate, so I used to get beat on. The next year, Anthony says to me, "I hope I have you again so I can play roller derby." It will be interesting to see the reactions of seventh period in September.

## Appendix

When we perform calculations, we must consider the accuracy of the numbers we are using. The accuracy of our results is determined by the accuracy of these numbers. The numbers that we used in our experiments were approximate numbers, since we used a measuring process to obtain them.

When we measured our course, we marked off ten yard intervals using a measuring tape. The ten yards were approximate. The tape may not be calibrated exactly or more likely may have stretched with usage. A more accurate measuring device may have given us different readings.

Temperature and humidity also affect measurement. Look at the difference in the sag of telephone wires between the winter and the summer. The lines are stretched tight in the winter, but droop in the summer. In the winter, the basketball that bounced fine in the gym appears to be flat when you take it outside. I see it in industry, where the factory conditions can affect a material to such an extent that the precision of the design is lost. An example of this would be the O-rings on the space shuttle.

The human factor also has to be considered. Today's stopwatches measure to hundredths of a second. Did my timers all start their watches at the same time? My son is a swimmer. At a swim meet, there are three timers in a lane. In most races there is a range of at least fifteen-hundredths of a second between the three watches. But, go back before the electronic stopwatches and stopwatches were only calibrated to a tenth of a second.

When we write a number, we have to be aware of how many of its digits are significant. All nonzero digits are significant. A trailing zero may be significant or it may be a placeholder. The accuracy of a number is determined by the number of significant digits it contains. The last significant digit of an approximate number is not completely accurate. It has usually been found by estimating or rounding off.

When we work with approximate numbers, we have to be careful about how we write our answers. Especially when using computers, the temptation is to express our answers with too many digits. Precision is related to accuracy. The precision of a number refers to the decimal position of its least significant digit.

When we work with approximate numbers, we should remember these rules:

1. When approximate numbers are added or subtracted, the result is expressed with the precision of the least precise number.
2. When approximate numbers are multiplied or divided, the result is expressed with the accuracy of the least accurate number.

It is important to remember the above. It is too easy to fall into the habit of thinking that the answer is accurate or precise to an indefinite degree because the computer did it. An even worse mistake though is to think that an answer is correct just because it was done on a computer.

*David Coasting Down a Slight Incline*

***(Distance vs. Time)***

| | Riding Position | | | Wearing |
|---|---|---|---|---|
| Distance (yds) | Normal (sec) | Streamline (sec) | Narrow (sec) | Coat (sec) |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10 | 4.49 | 4.27 | 3.77 | 4.81 |
| 20 | 8.79 | 6.40 | 5.77 | 7.17 |
| 30 | 8.74 | 8.19 | 7.43 | 9.22 |

| | | | | |
|---|---|---|---|---|
| 60 | 13.16 | 12.44 | 11.42 | 13.90 |
| 90 | 17.33 | 16.47 | 15.09 | 18.21 |
| 120 | 21.39 | 20.29 | 18.63 | 22.31 |

*David Coasting Down a Slight Incline*

***(Distance vs Average Velocity)***

Riding Position

Wearing

| Distance (yds) | Normal (ft/sec) | Streamline (ft/sec) | Narrow (ft/sec) | Coat (ft/sec) |
|---|---|---|---|---|
| 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 6.7 | 7.0 | 8.0 | 6.2 |
| 20 | 8.8 | 9.4 | 10.4 | 8.4 |
| 30 | 10.3 | 11.0 | 12.1 | 9.8 |
| 60 | 13.7 | 14.5 | 15.8 | 12.9 |
| 90 | 15.6 | 16.4 | 17.9 | 14.8 |
| 120 | 16.8 | 17.7 | 19.3 | 16.1 |

*David Coasting Down a Slight Incline*

***(Distance vs Instantaneous Velocity)***

Riding Position

Wearing

| Distance (yds) | Normal ft/sec) | Streamline (ft/sec) | Narrow (ft/sec) | Coat (ft/sec) |
|---|---|---|---|---|
| 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 6.7 | 7.0 | 8.0 | 6.2 |
| 20 | 13.0 | 14.1 | 15.0 | 12.7 |
| 30 | 15.4 | 16.8 | 18.1 | 14.6 |
| 60 | 20.4 | 21.2 | 22.6 | 19.2 |
| 90 | 21.6 | 22.3 | 24.5 | 20.9 |
| 120 | 22.2 | 23.6 | 25.4 | 22.0 |

*David Coasting Down a Slight Incline*

***(Distance vs Acceleration)***

Riding Position

Wearing

| Distance (yds) | Normal (ft/sec/sec) | Streamline (ft/sec/sec) | Narrow (ft/sec/sec) | Coat (ft/sec/sec) |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 1.5 | 1.6 | 2.1 | 1.3 |
| 20 | 2.8 | 3.3 | 3.5 | 2.7 |
| 30 | 1.2 | 1.5 | 1.9 | 0.9 |
| 60 | 1.1 | 1.0 | 1.1 | 1.0 |
| 90 | 0.3 | 0.3 | 0.5 | 0.4 |
| 120 | 0.1 | 0.3 | 0.3 | 0.3 |

*Kasey Pedaling*

***(Distance vs Time)***

| Distance (yds) | Time (sec) | Velocity Computed v=d/t (ft/sec) | Velocity from tangent (ft/sec) |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 10 | 3.52 | 8.5 | 10.7 |
| 20 | 5.67 | 14.0 | 17.1 |
| 30 | 6.99 | 22.7 | 21 |
| 60 | 10.05 | 29.4 | 30.5 |
| 90 | 13 | 30.5 | 32.1 |
| 120 | 15.87 | 31.4 | did not draw |

*Kasey Pedaling*

***(Velocity vs Time)***

Distance

from

| Velocity (ft/sec) | Time (sec) | Area A=(bl+b2)h/2 (ft) | Actual Distance (ft) |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 8.5 | 3.52 | 15 | 30 |
| 14.0 | 5.67 | 24 | 30 |
| 22.7 | 6.99 | 24 | 30 |
| 29.4 | 10.05 | 80 | 90 |
| 30.5 | 13 | 88 | 90 |
| 31.4 | 15.87 | 89 | 90 |

*(figure available in print form)*

*(figure available in print form)*

*(figure available in print form)*

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*(figure available in print form)*

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