Tracker: Teacher Notes

Introduction

The focus of this investigation is on gathering and analyzing data resulting from the motion of the students' own bodies and the motion of their low-friction air cart. Students will explore quantitative changes (e.g., rate, slope, acceleration, etc.) over time on a line graph. By using a SmartWheel connected to their handheld computer, the students will be able to make and compare different types of straight-line motions. By exploring position versus time and velocity versus time graphs, the students can explain and compare graphical displays, introducing terms meaningfully through experience.

In addition, students will gain experience with inquiry skills, including:

- knowing that an object's motion can be described by tracing and measuring its position over time;
- realizing that an object's motion can be described and represented graphically according to its position, direction of motion, and speed;
- knowing that when a force is applied to an object, the object either speeds up, slows down, or goes in a different direction;
- understanding the relationship between the strength of a force and its effect on an object (e.g., the greater the force, the greater the change in motion; the more massive the object, the smaller the effect of a given force);
- knowing that an object that is not being subjected to a force will continue to move at a constant speed and in a straight line;
- identifying variables that can affect the outcome of an experiment;
- understanding effects of balanced and unbalanced forces on an object's motion (e.g., if more than one force acts on an object along a straight line then the forces will reinforce or cancel one another, depending on their direction and magnitude; unbalanced forces such as friction will cause changes in the speed or direction on an object's motion);
- using technology (e.g., hand tools, measuring instruments, calculators, computers) and mathematics (e.g., measurement, formulas, charts, graphs) to perform accurate scientific investigations and communications;
- knowing that scientific investigations involve asking and answering a question;
- planning and conducting simple investigations (e.g., formulating hypotheses, designing and executing investigations, interprets data, synthesizing evidence into explanations, proposing alternative explanations for observations, critiquing explanations and procedures);
- establishing relationships based on evidence and logical argument (e.g., provides causes for effects);
- knowing that scientific inquiry includes evaluating results of scientific investigations, experiments, observations, theoretical and mathematical models,

and explanations proposed by other scientists (e.g., reviewing experimental procedures, examining evidence, identifying faulty reasoning, identifying statements that go beyond the evidence, suggesting alternative explanations).

Discussion Guide

Using this Guide

This guide is designed to help you convert the investigations your students experience into solid learning. The "Overview" section mentions some of the learning issues raised by this content. These issues might come up in conversations with students anytime. The "Setting the Stage" section provides ideas for a discussion you might hold before beginning the investigations. This discussion is important to motivate and alert students to observations that might answer their questions. The "Wrap Up" section can be used after the investigations to help student reflect on what they have done. Taking time to reflect while the investigations are fresh in students' minds has been shown to substantially increase learning.

Overview

While students need not understand the electronics, they need an operational understanding of what is going on to interpret the resulting graphs. You can do this by focusing student attention on the sensor and "playing" with the sensor to see what graphs can be produced.

Ask students to look carefully at the SmartWheel and come up with theories about how it works. Research has clearly shown that students should get a feel for graphs of their own motion before using the detector in an experiment. This is why the first trial involves walking with the detector, the second uses a cart kids pull, and the third involves a cart that moves on its own. That sequence should help students connect their kinesthetic experiences to the motion of the cart. Focus student thinking on the relationship between the motion and its graph. Give them practice predicting one and viewing the other. Once they make a measurement, be sure students review their prediction and think about what aspects of the prediction were right or wrong. Make a game of making accurate predictions.

Setting the Stage

A way to build understanding is to describe a motion and have students predict in advance what graph they will observe. A description might be "Your cart moves forward slowly until it has gone one meter. Then it stops for five seconds and roars backward quickly for two meters." Have students predict by sketching a graph on paper before doing the experiment. Then have them reflect on the differences between their predictions and observations. Their sketches won't be exact, but did they capture the main features?

Debating this helps students think about what the main features are. The particular motion described above introduces the idea of negative distance, something that students can find difficult. The end point of this motion is minus one meter and appears on the graph below the horizontal axis. Be sure to point this out. Continue to invent other situations that involve negative distance until students are comfortable with this idea.

Wrap Up

At the end of the trials, focus student attention again on the relationship between motion and its graph. Following are some ways to do this. Sketch a graph that all students can see, or use a projector so everyone can see a graph that you make. Then challenge each group to reproduce this graph by moving the cart by hand. This helps students connect the nature of the motion with the features on the graph. Ask students to identify what kind of motion resulted in each feature of the graph; each straight section, kink, peak, and valley. Ask what motion would result in steeply rising or falling sections, and how to create a graph with a continuously increasing or decreasing slope. A few minutes at this can do wonders for student ability to analyze graphs.

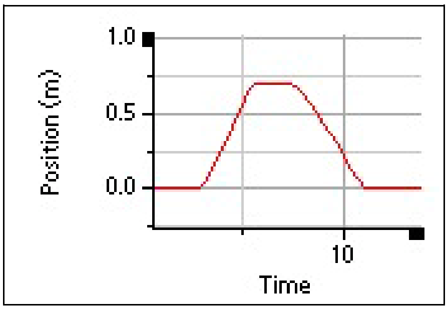
Challenge students to describe the difference between a rising and falling straight section of the graph that have the same angle. One represents a constant speed forward and the other the same speed backward. Scientists have introduced the term "velocity" just to cover both these situations. Velocity and speed are the same when the cart goes forward, but velocity is negative for the same speed backward. So, that line sloping downward is negative velocity. Try to get students to drop "speed" in favor of "velocity". The critical difference is that speed is always positive so it cannot distinguish between forward and backward motion. Velocity is better because backward motion is negative velocity.

The important velocity graph is introduced in the third trial. Focus student attention on this by sketching a position graph and having students predict the velocity graph. This is easy once you realize that the velocity is how fast the distance changes, so it depends on the slope of the position graph. If students don't agree on the velocity graph, have them do the experiment. Generate a position graph that approximates your sketch and use the computer to draw its velocity graph.

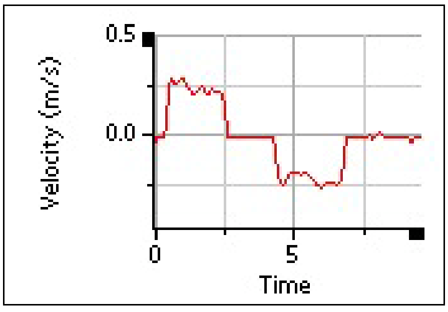
Additional Teacher Background

This investigation introduces the SmartWheel as a tool for exploring how to measure motion. The motion of an object is where it is, how fast it's moving, and in what direction - that is, its position and its velocity. The SmartWheel measures how many times the wheel turns and how fast it's turning. If it's running along the ground, these measurements can be converted into distance and speed. Are these the same as position and velocity? This question raises basic and challenging issues.

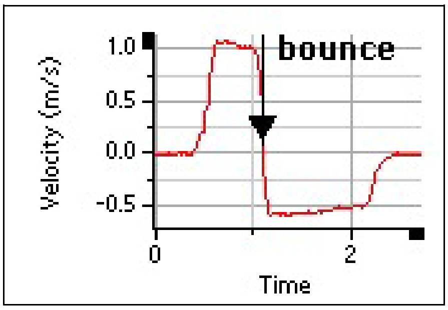
The SmartWheel, like a car's odometer, measures the distance the wheel has traveled along the ground. Unlike the odometer, however, the SmartWheel will subtract distance if it rotates in reverse. If the SmartWheel is run along a straight line, the position measurement will increase if you go in one direction and decrease if you go in the other, whereas the distance you traveled will always increase. If you go 10km in a car and then turn around and go back to where you began, you will have gone a distance of 20km, but your position will increase to 10km then back down to 0m. Position can be either positive or negative. In simple terms, distance is how far you travel, and position is where you are at each instant relative to your starting point. Here's an example of going in one direction, stopping and then returning to the starting location.



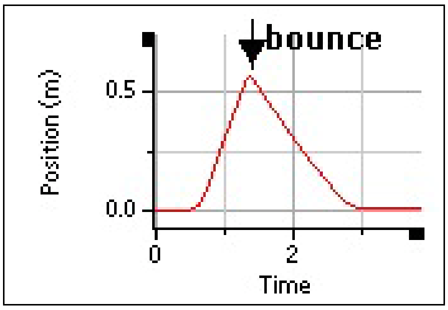
A similar distinction can be made between speed and velocity. Speed is how fast you're going (change in distance / change in time), regardless of what direction you're going. A car's speedometer measures speed. Velocity, however, has two parts: speed and direction. "Driving north at 30km/hr" is a velocity, and it's different from "driving west at 30km/hr. " In the above example, the velocity is positive as you go forward and your position increases. It's zero when you stop. Then it's negative as you go backward and your position decreases.



If your cart bounces off a wall, it might have similar speeds before and after the bounce, but its velocity has reversed direction. This will be shown on the SmartWheel graph as a positive velocity before the collision and a negative velocity afterwards. The position graph will increase, then decrease as the cart rolls backwards.



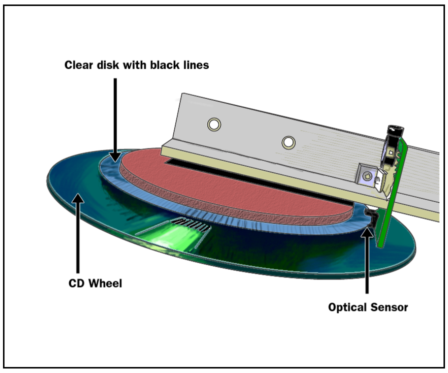
When the SmartWheel is used for one-dimensional motion along a straight line, position can be thought of as the distance, positive or negative, from the starting point. Velocity can be thought of as either positive or negative speed, where positive velocity increases position, and negative velocity decreases position.



Motion in two or three dimensions, such a circular motion, is not explored in these Investigations. It may come up, however. For example, suppose you're driving a car in a circle at 30km/hr. Your distance from the center and your speed are both constant. But your position is certainly changing, and your velocity is changing because your direction of travel is not constant.

A central challenge for students is to understand the relationship between a position graph and a velocity graph for the same motion. Since velocity is change in position divided by change in time, velocity is the slope of the position versus time graph. For instance, a steadily rising straight-line position graph is equivalent to a level and positive velocity graph. A steadily falling straight-line position graph is equivalent to a level and negative velocity graph. A steeper position graph means a greater constant velocity. If the position graph is level, the velocity graph is zero.

Going one step farther, a steadily changing velocity implies a constant acceleration. It also implies that the slope of the position graph is changing, so it will not be a straight line. It will be a parabola. Students will observe this if they let the cart roll up and down a ramp, or run it with the propeller. There are many situations in science where one quantity is the rate of change of another (e.g. acceleration and velocity, power and energy, heat quantity and heat flow, population and birth rate), and this is also what calculus is all about.



Sophisticated electronics are used to sense the rotation of the SmartWheel and use that data to generate a graph on the computer. An invisible infrared beam is directed through the clear plastic disk that has regular black lines printed on it. A sensor detects when a black line blocks the beam. Each time the beam is blocked means the wheel is turned a bit. The computer simply counts how many times the beam is blocked. There are actually two beams and this allows the computer to figure out which way the wheel is turning. If the wheel is turning one direction, the computer adds 1 each time the beam is blocked, but if it turns the other direction, it subtracts 1. The computer program interprets this information either as position (how many black lines go by) or as velocity (how fast the black lines go by).

Suggested Timeline

The amount of time you spend on introductory discussions, data collection, and analysis, will determine your overall timeline. The following represents a possible timeline.

One class period - "Setting Up" discussion

One class period - Trial I: Walking off distances

One class period - Trial II: Rolling cart

One class period - Trial III: Rolling to a stop

One class period - Analysis and "Wrap Up" discussion

Additional days can be used for Further Investigations.

