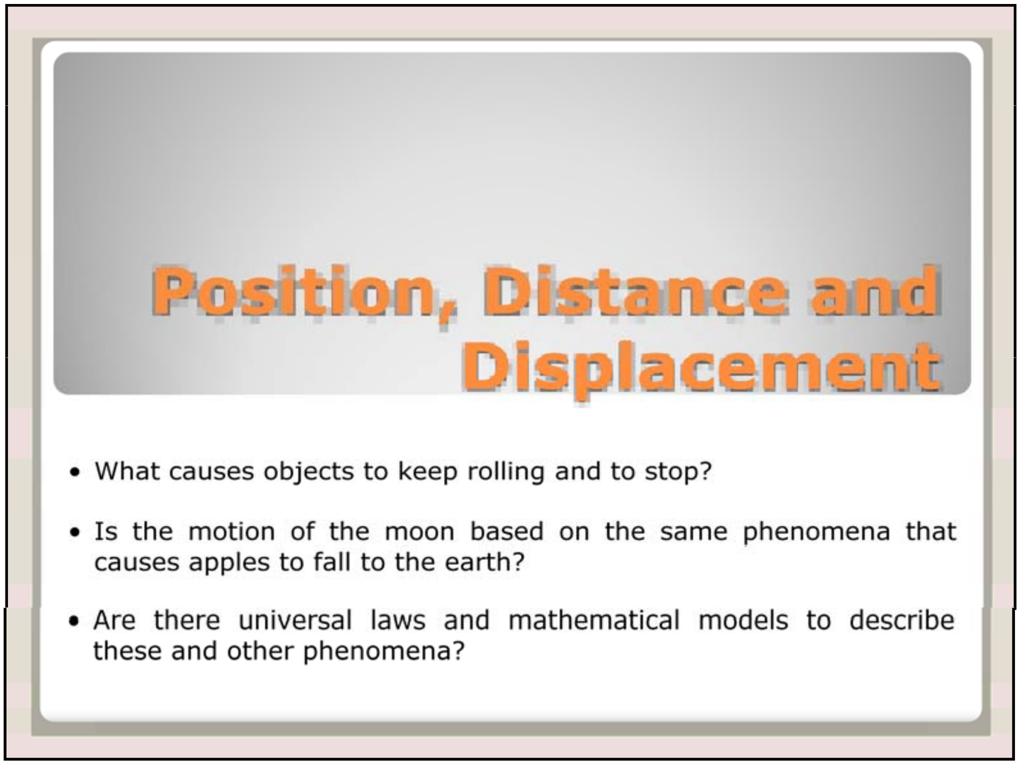
Module 1: Describing Motion

Topic 1 Content: Position, Distance and Displacement



The development of physics as a discipline can be traced to several innovative thinkers who began to develop and apply the scientific method to investigations of everyday phenomena. Some of the initial questions raised by Galileo and Newton involved the motion of objects on earth, in flight, and through space.

•What causes objects to keep rolling and to stop?
•Is the motion of the moon based on the same phenomena that causes apples to fall to the earth?
•Are there universal laws and mathematical models to describe these and other phenomena?

As we begin our investigation of physics, we will start by learning how to describe and analyze the motion of everyday objects.

Module 1: Describing Motion

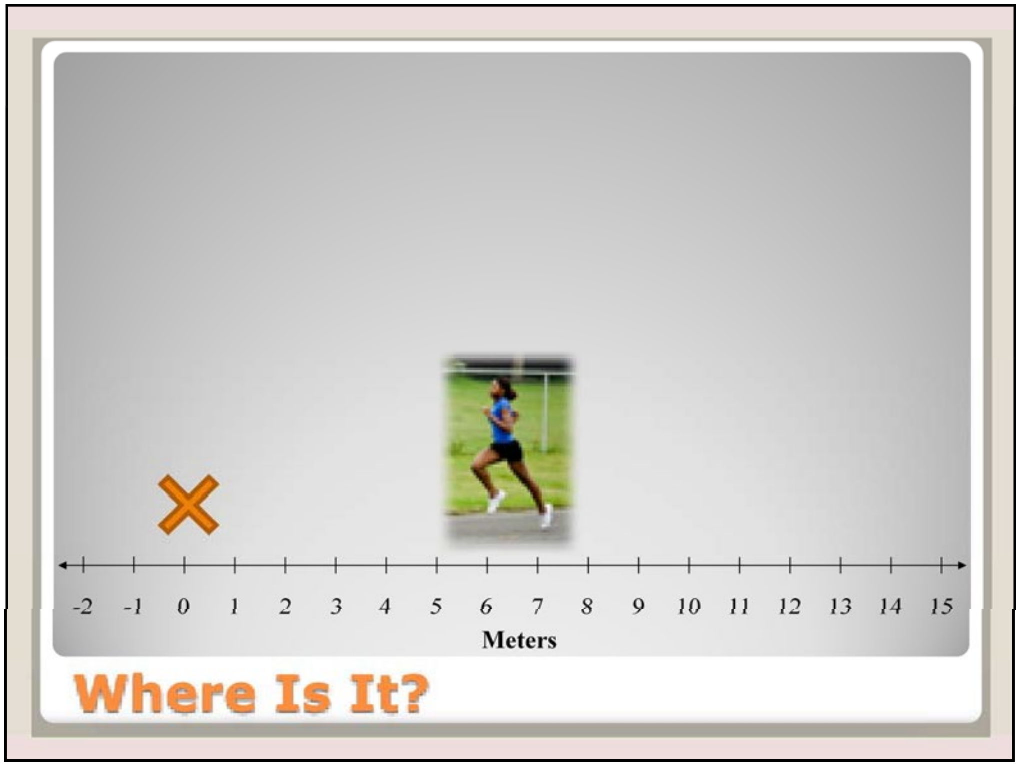
Topic 1 Content: Position, Distance and Displacement

- A sprinter running 100 meters
- A dragster running the quarter mile
- A baseball player stealing third base
- A soccer ball kicked past the goalie

What do all these objects have in common? They are objects in motion. In physics, we are interested in understanding the way objects behave. In order to do this, we have to be able toanalyze their motion over time, so we can predict their behavior under new circumstances.

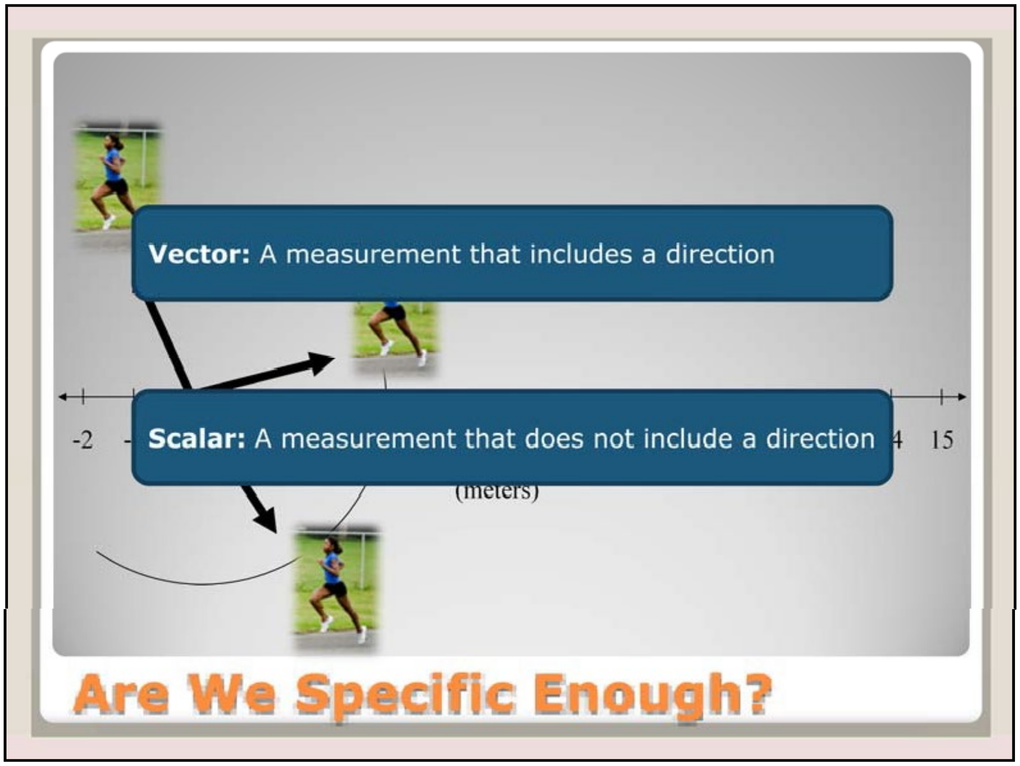
Module 1: Describing Motion
Topic 1 Content: Position, Distance and Displacement

Our first challenge in describing the motion of an object is to be able to clearly state where the object is. Take a moment to try to describe where the runner is. You might say "she is on (or above) the track." You could be tempted to describe her as "near the center or bottom of the screen!" But it is more useful to us in physics to describe the location of an object with respect to a specified point, or "origin". This could be the starting line or the finish line. It could be her position compared to another runner, or her coach, or the next hurdle. We could even measure her position compared to the Washington Monument. One great thing about physics is that analyzing from any of these points will be completely equivalent to analyzing from any other point, although you'll find out quickly that some of the choices are much more useful than others.



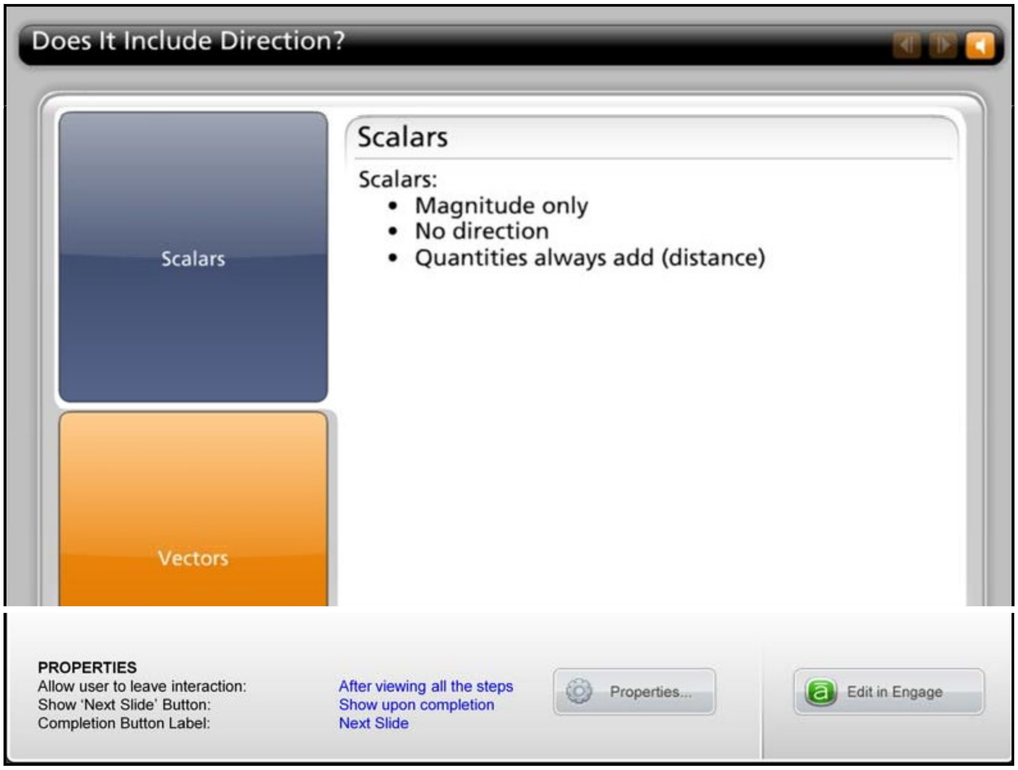
In this case, we'll just choose a convenient point to use as the point from which we'll compare the runner's position, and mark that point with an “x”. Now, where is the runner? Perhaps the best you can say is that she's “somewhere to the right of x,” but this still leaves a lot of possibilities open. In order to get more specific, we will make use of the number line that we learned back in elementary school math.

And, if we also include units, we can be quite specific with the location of the runner. In this case, we can say that the runner is six meters from the “x”. Or, we can remember that we call the “x” the origin and say that the runner is six meters from the origin. In this case, the origin is not necessarily the start of the race, but it would have been convenient to choose that point from which to measure. Now, are we certain that we're specific enough?



What if we said that there was a runner located four meters from the origin? She might be here. But, she also might be here! Or here!

Each of these locations is a distance of four meters from the origin. So, it looks like in addition to distance, we also need to specify direction. A measurement that includes a direction has a special name in physics; we call it a "vector". Measurements without directions are called "scalars".



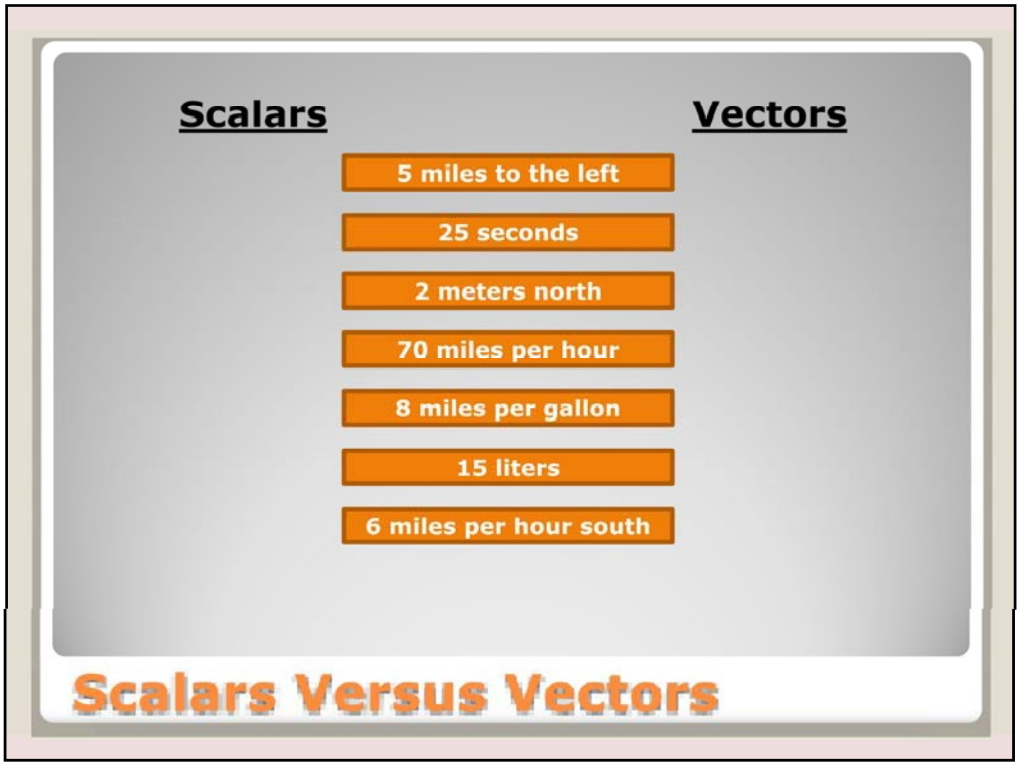
Tab: Scalars

Scalars have magnitude only but do not include direction, and the quantities continue to add.

Tab: Vectors

Vectors include magnitude and direction and the quantities have the ability to partially or totally cancel out when the quantities are in opposite directions.

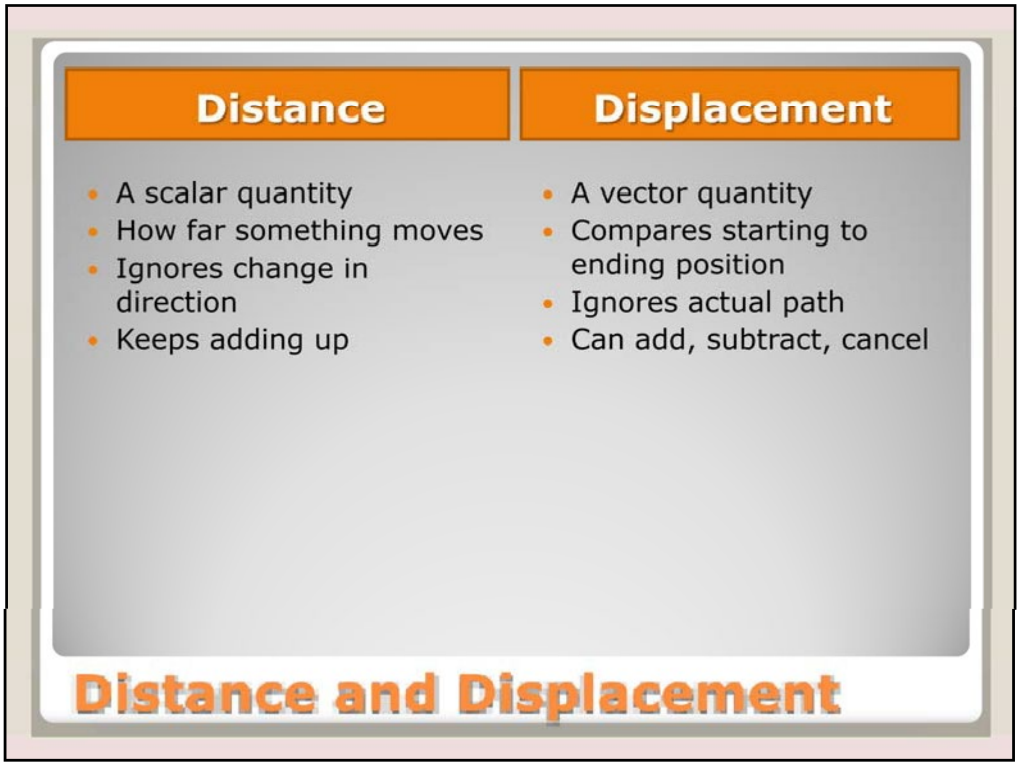
Module 1: Describing Motion
Topic 1 Content: Position, Distance and Displacement



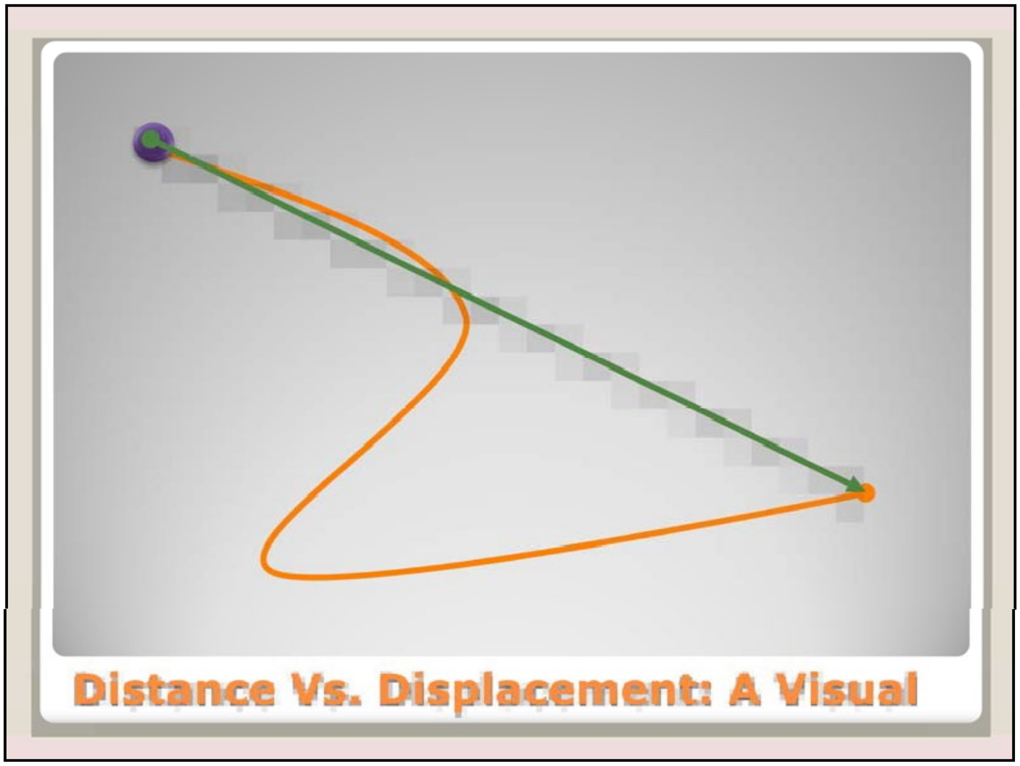
Take a look at the measurements and determine if they are scalars or vectors

•5 miles to the left is a vector, since it includes the direction “to the left”.
•25 seconds is a measure of time. Even though time is said to flow “forwards” and we talk of going “backwards” in time, we will consider time a scalar quantity.
•2 meters north is a vector since it includes the direction “north”.
•70 miles per hour is a scalar quantity because it does not include a direction.
•8 miles per gallon is a scalar quantity. It also wouldn’t make sense as a vector because you can’t point in a direction representing 8 miles per gallon.
•15 liters is a scalar quantity. Certain measures, such as mass, volume, time and energy exist independent of direction, so will always be scalar.
•6 miles per hour south is a vector quantity since it includes the direction “south”.

Now, let’s take a look at why these distinctions are important.



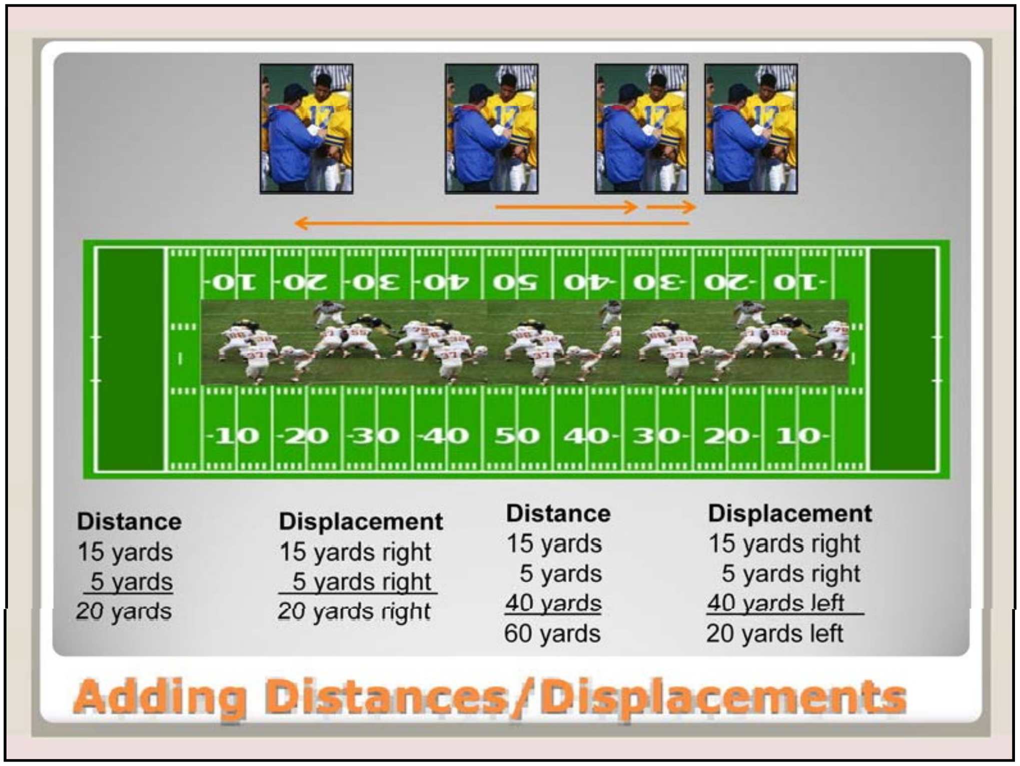
The words distance and displacement may sound like synonyms in normal usage, but to a physicist, they are very different. Distance is a scalar quantity, recording how far something moves, but ignoring any changes in direction. Displacement is a vector quantity that compares an object's position at some later time to its position at some earlier time, regardless of the path it may have taken. You'll quickly see that distances keep adding up, while displacements, which include direction, can add or subtract.



Shown here is a visual representation of the difference between distance and displacement. In this animation, the distance is shown by the length of the orange line on which the purple circle travels. The green line shows the length and the direction of the displacement.

Module 1: Describing Motion

Topic 1 Content: Position, Distance and Displacement

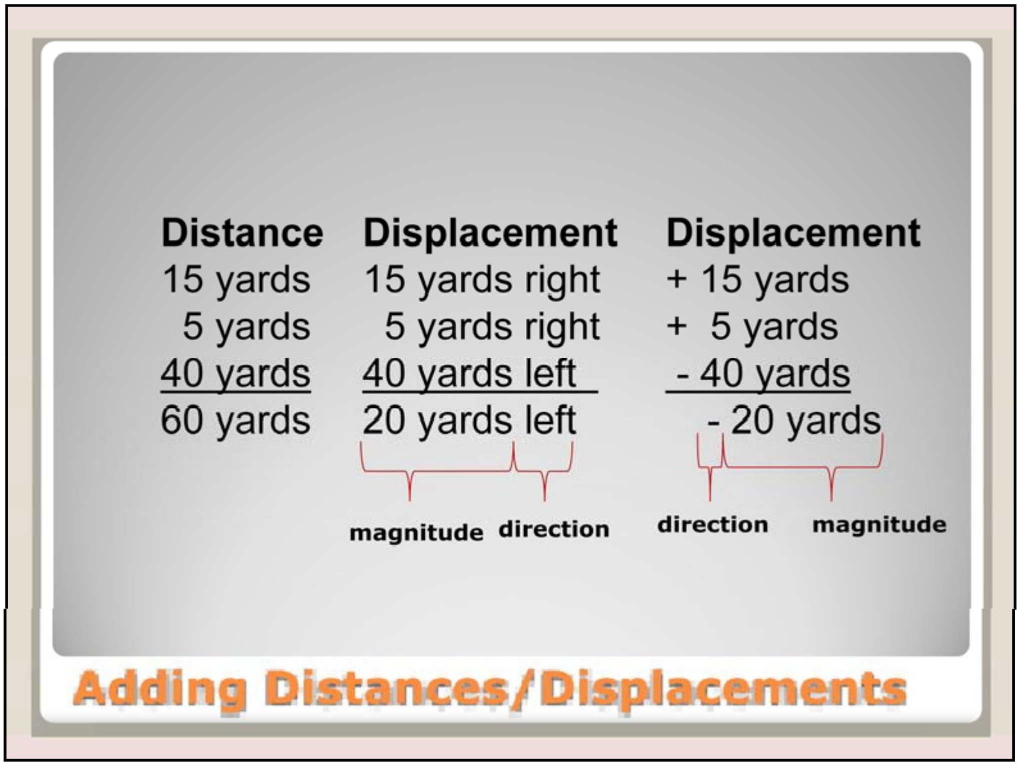


Let's look at an example. You may have noticed that during a football game, the coach tends to move up and down the field along with the team, so that he's nearly always standing right at the line of scrimmage. Let's follow a coach during a few plays in a game.

In the first play, his team completes a pass and moves fifteen yards to the right. The coach moves fifteen yards to the right along with his team. The total distance moved by the coach is fifteen yards, and the total displacement of the coach is fifteen yards to the right.

In the next play, the team again advances with a five yard run, so the coach walks an additional five yards to the right. The total distance traveled by the coach is now 20 yards, and his total displacement from his starting point is 20 yards to the right.

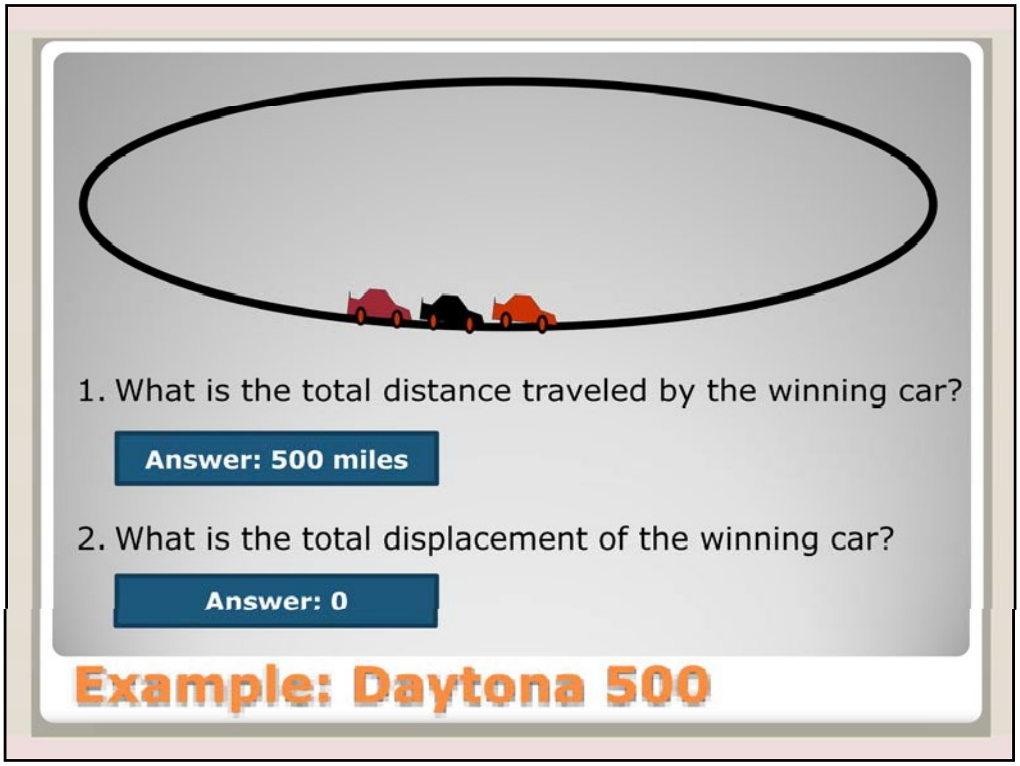
However, in the next play, the quarterback fumbles and then recovers the ball, but in the process, loses 40 yards on the field. The coach now walks an additional 40 yards to get to the new line of scrimmage. The total distance walked by the coach is now 60 yards. However, the coach is now only 20 yards from his starting point. The total displacement of the coach is only 20 yards, even though he walked a total distance of 60 yards. This is a key difference between scalars and vectors.



Another, more powerful way of representing right and left is to think back to the number line and call the right "positive" and the left "negative". The result is that the total displacement in this case is negative twenty yards. Of course, we could have chosen left to be positive and right to be negative, in which case the total displacement would have been positive 20 yards. And if you were the coach of the opposing team, maybe this is precisely how you'd see it! Choosing a positive direction instead of referring to "left and right" will become very convenient as we continue to deal with straight-line motion.

Also, note that each vector, such as displacement, is a combination of a magnitude and a direction. The magnitude indicates how much and can be considered the absolute value of the displacement. Here, the magnitude of the displacement is 20 yards, and the direction is either left or negative.

Module 1: Describing Motion
Topic 1 Content: Position, Distance and Displacement

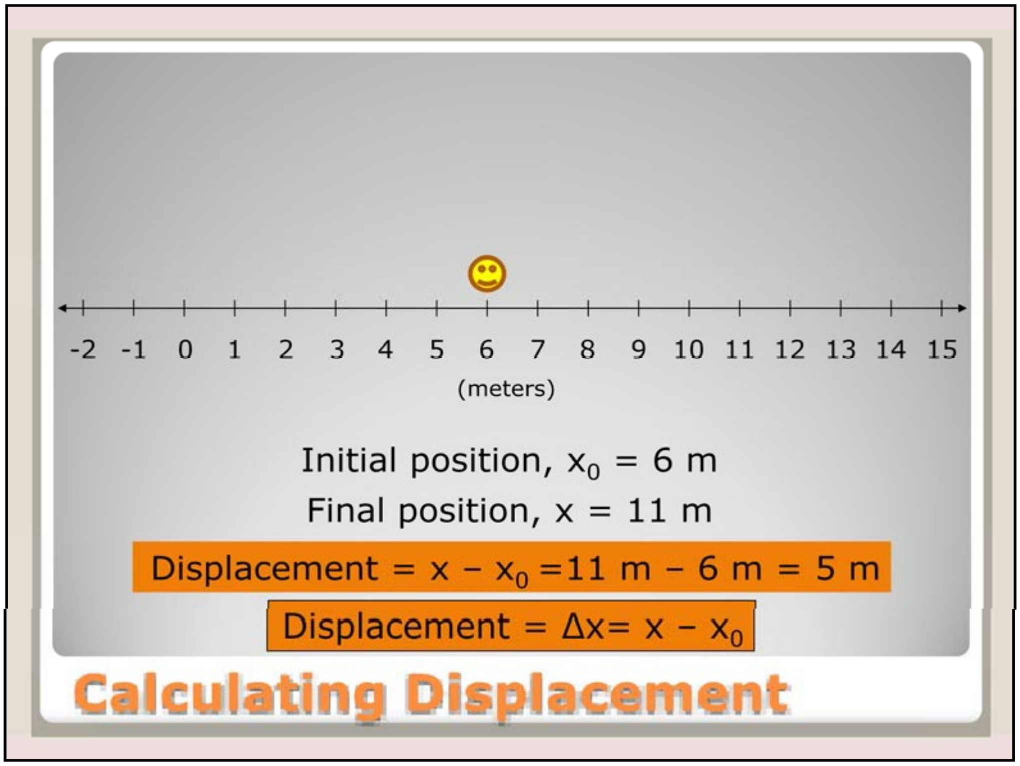


For a final example, look at the Daytona 500. What is the total (scalar) distance traveled by the winning car from the start to the end of the race? Since the Daytona 500 is 500 miles, the total distance travelled is 500 miles!

What is the total displacement of the winning car from the start to the end of the race? Since they start and finish at the same place the total displacement is 0 miles! Since the winning car starts and finishes the race at the same place, the final displacement is zero.

Module 1: Describing Motion

Topic 1 Content: Position, Distance and Displacement



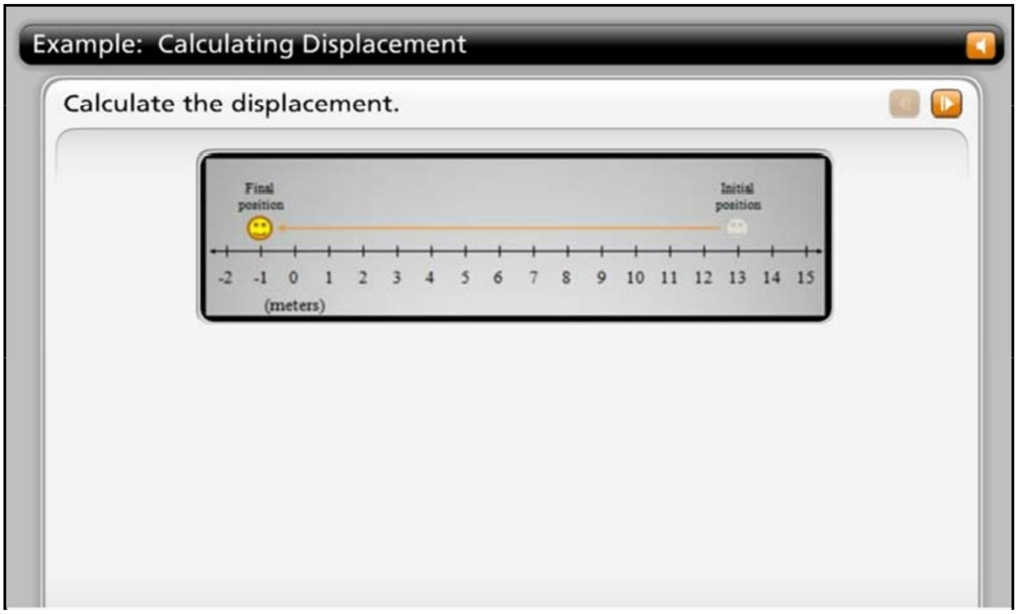
When we need to be specific about calculating displacement, we can use a formula to represent the relationship that you have already learned. To calculate the total displacement, we simply need to compare the initial position to the final position and determine the difference and the direction. We need to determine a reference point, the origin and we need then to specify a positive direction and pick units, just as we did before.

Later, we'll be interested in motion in two dimensions, so we'll add another number line, or axis, in the vertical direction. That will be the y-axis, so we'll call this the x-axis. The initial position of the object will be assigned a variable. Since this is the x-axis, we'll give the position the variable x. To specify that this is the initial position, we'll put a small number zero as a subscript and call that x zero. In this case, x zero equals positive six meters. The positive represents the direction "to the right" to distinguish it from a negative direction, which would be "to the left".

At a later time, the object is at a new position. We'll call this the final position. We represent the final position as simply x without a subscript. In this case, x equals positive eleven meters.

Now you should be able to see that the displacement in this situation is five meters to the right, or plus 5 meters. Specifically, the displacement has a magnitude of 5 meters and is in the positive direction. To get plus five from six and eleven, you clearly have to subtract six from eleven because eleven minus six equals five. So, the displacement is going to equal x minus x zero. Notice that this equation didn't just "come out of nowhere", but it is a mathematical representation of a relationship that we were interested in. All of our equations in physics are like this – they express relationships between two or more measurements or variables.

A fancy way of representing the amount that a variable changes is by writing the greek letter Delta, which is simply a triangle. So we can say that the change in position, or the displacement, is Delta x, which equals the final position minus the initial position.



Introduction

Now you try to calculate a displacement. In this case, the object will move to the left. Think about what the answer should be before you even write anything down.

Step One:

Since it is moving to the left, the answer should be negative, and if we count how far it moves, we see it moves 13 meters to zero, and then another meter to negative 1, for a total of 14 meters, so the answer should be fourteen meters to the left, or negative fourteen meters. Does this agree with our formula? Let's see. Our first step was drawing a picture and predicting the answer. The next step is to write down a table of variables. Identify each value we know and assign the proper variable to that value. Here, the object starts at positive 13 meters, so we have an initial position. We write x zero equals 13 meters.

Step Two:

The final position of the object is at negative one meter. This is the final position, so we write x equals negative 1 meter.

Step Three:

The next step is to identify the proper equation that shows the relationship we are looking for. At this point, we only have one equation, so we write it down in its raw form without any numbers in it.

Step Four:

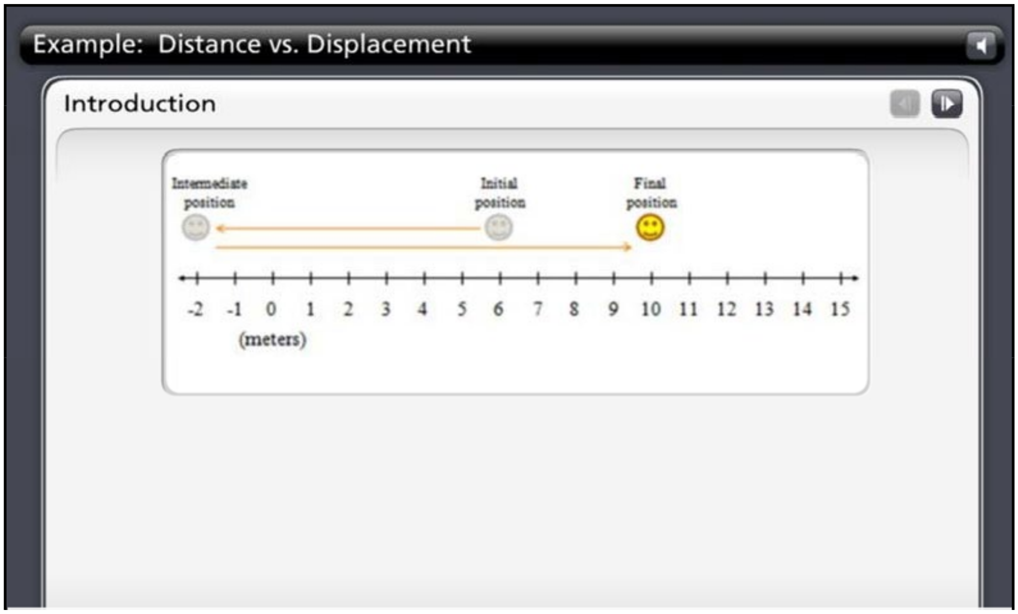
Now we're ready to substitute our values into our equation and we find that the calculated answer agrees with our prediction. The displacement is negative fourteen meters. Again, the negative sign represents a displacement to the left since our axis or number line here increases as we go to the right.

Step Five:

What about distance traveled? Remember that distance is a scalar, so direction doesn't matter. In this case, although the displacement was negative 14 meters, where the negative meant "to the left", the distance traveled is simply 14 meters, since we don't need to include the direction. To distinguish distance from displacement, we will use the letter *d* for distance. So *d* equals 14 meters.

Module 1: Describing Motion

Topic 1 Content: Position, Distance and Placement



Introduction:

To see more clearly the difference between distance and displacement, let's look at another example. In this case, the object will start at positive six meters, will move first to negative 2 meters, then will move again and wind up at plus ten meters.

Step One:

Let's calculate each displacement and add them together, then we'll do the same for distance. The first displacement is when the object moves from plus six to negative two. x zero equals plus six, x equals negative two. We'll use our displacement equation again, substitute and find that the displacement equals negative 8 meters. How far did the object move? The distance traveled equals 8 meters.

Step Two:

To calculate the second displacement, we've got to look at the new initial and final position. Here, the object starts at negative 2 meters and ends at plus ten meters. So, x zero equals negative two and x equals ten. Plugging this into our displacement equation results in a displacement of positive twelve meters. The distance traveled here is simply twelve meters.

Step Three:

Now, let's add our displacements to get our total displacement. Our first displacement was negative eight and our second displacement was positive 12. These add to positive four meters

Step Four:

For the total distance traveled, however, we add 8 to 12 and get a total of 20 meters.

Step Five:

You may have discovered a shortcut to calculating total displacement. We didn't need to consider the intermediate position. We could just compare the initial position to the final position. You see that we still wind up with 4 meters. This shortcut only works for displacement, but not for distance.