This is a bungee jumper at the bottom of his trajectory. This is a pack of dogs pulling a sled. And this is a golf ball about to be struck. All of these scenarios can be represented by free body diagrams. Physical problems -- for example, calculating the force on the bungee jumper by the bungee cord -- are much easier to solve once you've drawn a complete and correct free body diagram.

This video is part of the Representations video series.

Information can be represented in words, through mathematical symbols, graphically, or in 3-D models. Representations are used to develop a deeper and more flexible understanding of objects, systems, and processes.

Hello. My name is John Belcher. I am a professor in the physics department at MIT, and today I'll be talking with you about free body diagrams. Physics uses many different representations to aid with problem solving. Free body diagrams allow us to represent the forces on an object, thus enhancing our understanding of situations and helping us to solve problems. Studies have shown that students who understand and use free body diagrams tend to score better on homework, quizzes, and exams. Such representations can be powerful tools for solving problems, and remain useful even for physics experts.

Our objectives are to improve your skill with free body diagrams and to show some of the connections between them and the physical situations they represent. I hope you find it useful.

We're going to assume that you have drawn a few free body diagrams in the past, so this video will start with only a short refresher of how to draw them before getting into some more difficult and detailed problems. Here are some guidelines to remember when drawing your free-body diagram. Rather than trying to sketch an object in detail, we're always going to draw it as a single point. We focus on a single moment in time. Our diagram will only include forces, and not any other vectors or any other quantities. The arrows we draw for the forces will be longer for stronger forces, and we'll always draw them as coming from the object. Finally, we'll want to draw only forces with a substantial impact on the object's behavior, and leave out any that are negligible.

The forces we'll consider today are primarily those we see in the world around us: gravity, the normal force, tension, hands pushing or pulling, friction, and so forth. We won't be talking about things like the magnetic force, buoyancy, and so forth, but when you encounter those in your courses, they can be treated in exactly the same manner as the forces you'll see today.

To keep the length of this video down, we've had to leave some things out. The first is anything to do with circular motion, including torque or centripetal force. Dealing with torque requires a more complex approach that you'll learn later on in your course. The second is a complete lesson on how to deal with angles in forces and free body diagrams.

That is something that you will need to practice on your own in order to really understand well.

Let's do a quick refresher on how to draw free-body diagrams. We'll walk through them one step at a time. If you have some paper available you should draw the diagrams yourself as we go through the steps.

This is very basic example: a falling block. If we ignore air resistance, this is an object with just one force applied: the force of gravity. We're going to...

draw the object as a point, draw the force of gravity as an arrow, and label our force. We're done.

Let's build up to a more complex example. Here's the block on a table, stationary.

We need to draw the object as a point, and draw the force of gravity pulling down on it.

Our block is stationary, which means that it is not accelerating. No acceleration means a total force of zero, so we must have at least one more force in place to cancel out the force of gravity. In this case, that cancellation is provided by the normal force from the table.

Let's draw in the normal force.

If we wanted to have a hand pushing the object...

...we can adjust our existing diagram to include that. All we need to do is add an arrow to indicate the force provided by the hand.

We can also tilt the table upwards and push the box up the slope. As you can see, this tilt changes the direction of our normal force, but not the force of gravity.

We could also include friction from the surface if we wanted to be more realistic. Now we have a fairly complex diagram that visually represents many different forces on our object.

Now we're going to show a couple of real-world examples, and show how we would diagram them.

Here's a bungee jumper. This is a very dynamic situation. It's important for us to choose a particular time during the jump at which to draw our diagram, because the forces will be very different at different times. We can choose any time we like, but we do have to pick just one time. Let's say that we're interested in the time when the jumper is at the bottom of his trajectory.

Again, we start with a dot. We don't draw a stick figure, just a single point. And we don't include the rope, even though it is important. We just draw the object in question -- the jumper.

Gravity is clearly an important force, as is the tension from the bungee cord. To determine the strength of the tension, we must decide what the acceleration of the jumper is. Pause the video to consider this.

At the bottom of the arc the jumper must be accelerating upwards, so as to bounce up.

Therefore, we make sure to draw tension as being stronger than the force of gravity.

Looking at the diagram at different points during the fall would give us different amounts of force. Even though we might like to represent that, it doesn't belong on our diagram. Free body diagrams are drawn at a single point in time.

This example involves a dog sled.

Let's draw a diagram of the sled as the dogs pull it across the snow at constant velocity.

Here's the sled, "with gravity pulling down, and the normal force pushing upwards.

Here is the force from the dogs, pulling the cart forward.

The sled is moving at constant velocity; therefore the sled has no acceleration.

Therefore, the total force on the sled must be zero. Right now our forces are unbalanced, so there must be another force we haven't drawn yet in order to balance out the pull.

That's the force of friction between the sled and the snow.

Once we draw that in, we're done.

Since we know that the sled is moving at constant velocity, the sum of our forces should be zero.

Here's another example: a golf swing. Let's say that we want to draw a free body diagram of the ball just after it loses contact with the ground.

You can see that the photo is not at a great angle for us to see what's going on, so let's draw a sketch to help us picture it.

We'll start the diagram with a point representing the ball...

...and drawing the force of gravity.

The contact force between the ball and the club will be perpendicular to the club, so we need to be careful to make sure our angles match. We also need to draw a fairly long arrow to represent a strong force, because the hit from the club is lifting the ball off the ground. We need to make sure that the vertical part of the club's force is stronger than the force of gravity.

Since the ball is no longer in contact with the ground, there will be no normal force from the grass. We're all done.

Now we're going to look at some typical mistakes that people make when drawing free-body diagrams.

This is to help you catch errors in your own work, as well as to assist others during group work. Many errors come from breaking the guidelines we set forth earlier, so watch for places where those are broken as we go through this sequence.

The diagrams we'll show here each have issues with them. To remind you of this, we'll put a red exclamation point in the bottom right corner of the screen.

If you're watching this on your own, pause the video when a new example appears, to try to find out what's wrong.

When we correct the diagram, we'll change the exclamation point to a green check-mark.

Here's a diagram with a problem. In this situation we're trying to show the forces on the ball after it is thrown. Try to spot the error.

The diagram shows gravity pulling down, and air resistance at work, but a 'throwing force' is also included.

Because the diagram is intended to be drawn after the ball leaves the pitcher's hand, that force has already done its job. There's no need to include it here. Newton's First Law tells us that the ball will keep moving; it doesn't need an extra force pushing it along all the time.

Now the diagram is correct.

Here's our example of a block on a tilted table from before. We've drawn in a coordinate system to show the x and y directions. We can see that there are several forces at work: the pushing hand, the normal force, friction, and gravity.

However, there seem to be three gravitational forces at work: one pulling straight down, one pulling against the normal force, and one pulling down the slope. It seems as if the gravitational force has been decomposed into x and y components, and then also left on the diagram. Once a force has been decomposed, the original should be removed.

That's better.

Here's a diagram of a car driving on the highway. Can you tell what's wrong here?

We have gravity, friction, and a force moving the car forward, but this arrows seems to represent a velocity. It might be useful information, but it's not something that gets included on a free body diagram. Free body diagrams only include forces.

Let's remove it.

That's better. But we're not done yet. According to the diagram, this car is accelerating downward -- it's falling through the road." "We need a force to balance out gravity. The car is in contact with the road, so there must be a normal force.

There we go. Much better.

Here's our final bad example.

It looks like whoever drew this was trying to list every force they could think of. Earth's gravity is something we almost always include, and one can understand including air resistance for a parachute, but this diagram also has gravity from the moon, gravity from the sun, a buoyant force, force from the wind, aerodynamic lift, and whatever this F-Z is! We're practically out of space. One key to drawing a free body diagram is narrowing down your forces to just those that apply to the problem at hand. Are all these forces present? Probably, yes. Are all of them important in your current situation?

Probably not.

Simplification is an important part of physics. The more complex we make things, the harder our problems will be to solve. If our problem tells us to keep air resistance, we'll use that, and ignore other forces.

Now we're going to look into what our diagrams tell us about a physical setup. This will help us refine our understanding of these diagrams. After all, if a free body diagram is really a representation of what's going on, it should have a strong connection to a physical situation.

Here's a car on the highway. This animation will help us understand the changes in our diagram.

We can tell that this car is not accelerating. The forces in our y direction balance, and the forces in our x direction balance.

That means that if we remove or change any of these forces, the car should accelerate.

For instance, if we reduce the force of friction, the car will speed up.

We could also speed up the car by applying more force in the forward direction.

Removing the force that's pushing the car forward results in the opposite effect.

The car will eventually slow to a halt.

Finally, without the normal force, there's nothing to stop gravity from accelerating the car downward.

You can see how any change in the physical forces applied can be represented on the free body diagram.

As useful as they are, there are some situations in which a free body diagram is not the right tool for the job.

Some situations are so simple that they may not warrant a diagram. There's no harm in drawing it, especially when you're starting out, but as you become more skilled you may be able to do without it.

Some situations are better solved with a different approach entirely. This exercise, for example, calls for the use of a different principle: conservation of energy. A free body diagram is not likely to shed much light on the problem.

This problem involves rotation and torque. Free body diagrams work best with linear motion.

Even though force is involved, a free body diagram may not help.

However, a more sophisticated diagram may be of assistance. This one shows where the forces are applied to the bar, and can be used in the calculation of torques. You can see that it is very different from a free body diagram. Free body diagrams are only one type of representation, and it is important to choose the right representation for your purpose.

Now you've seen how to represent physical situations with free body diagrams, and gained some greater insight into their use. The ability to use and analyze free body diagrams is a skill that remains useful to physicists and engineers at all levels of experience. Your expertise with them will improve with practice. I hope this video has helped to improve your understanding of free body diagrams and their uses.