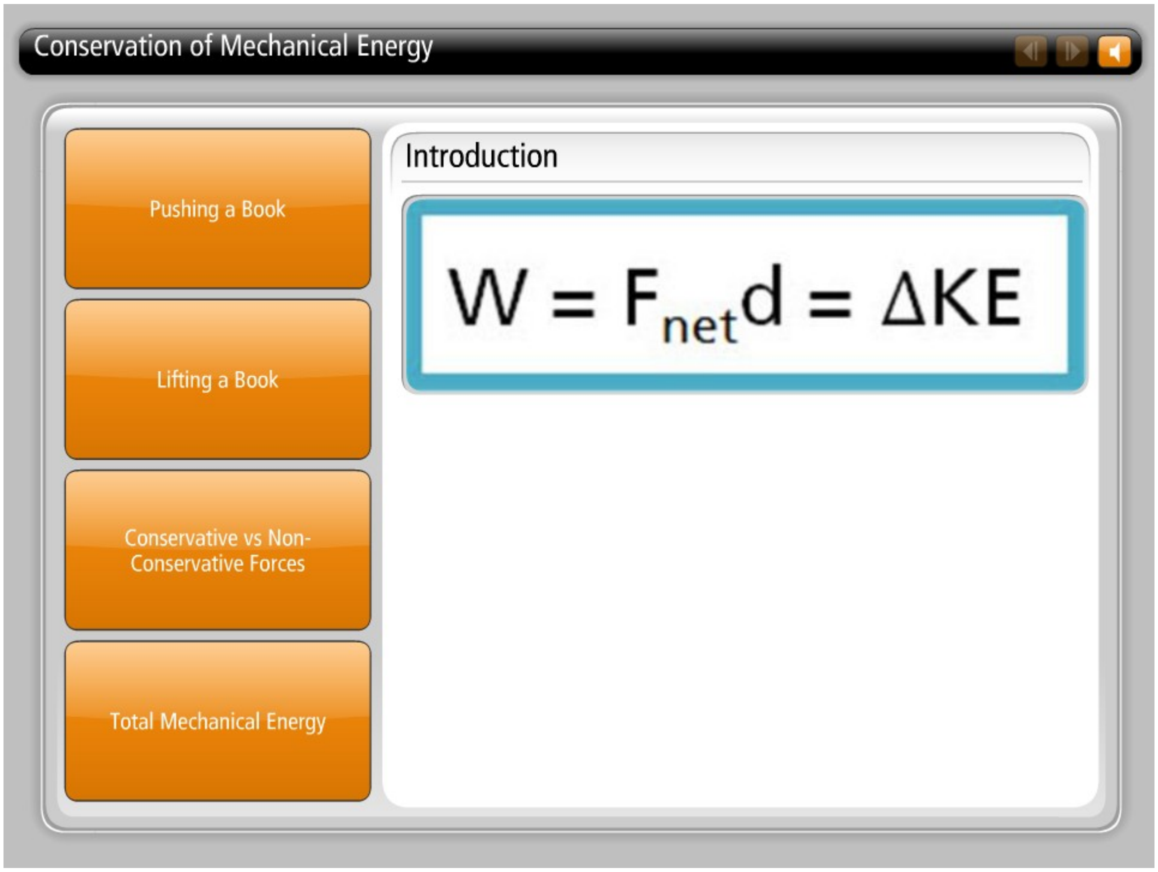
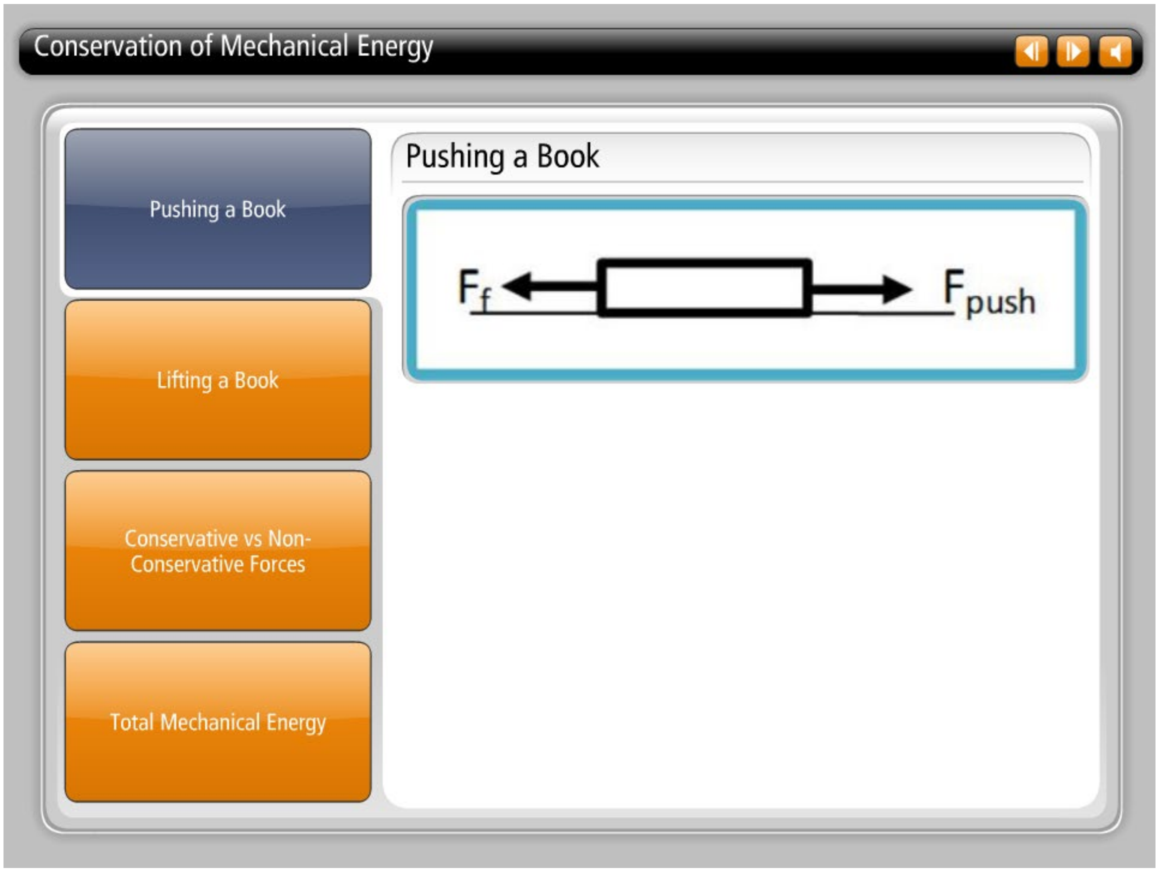
Module 4: Energy

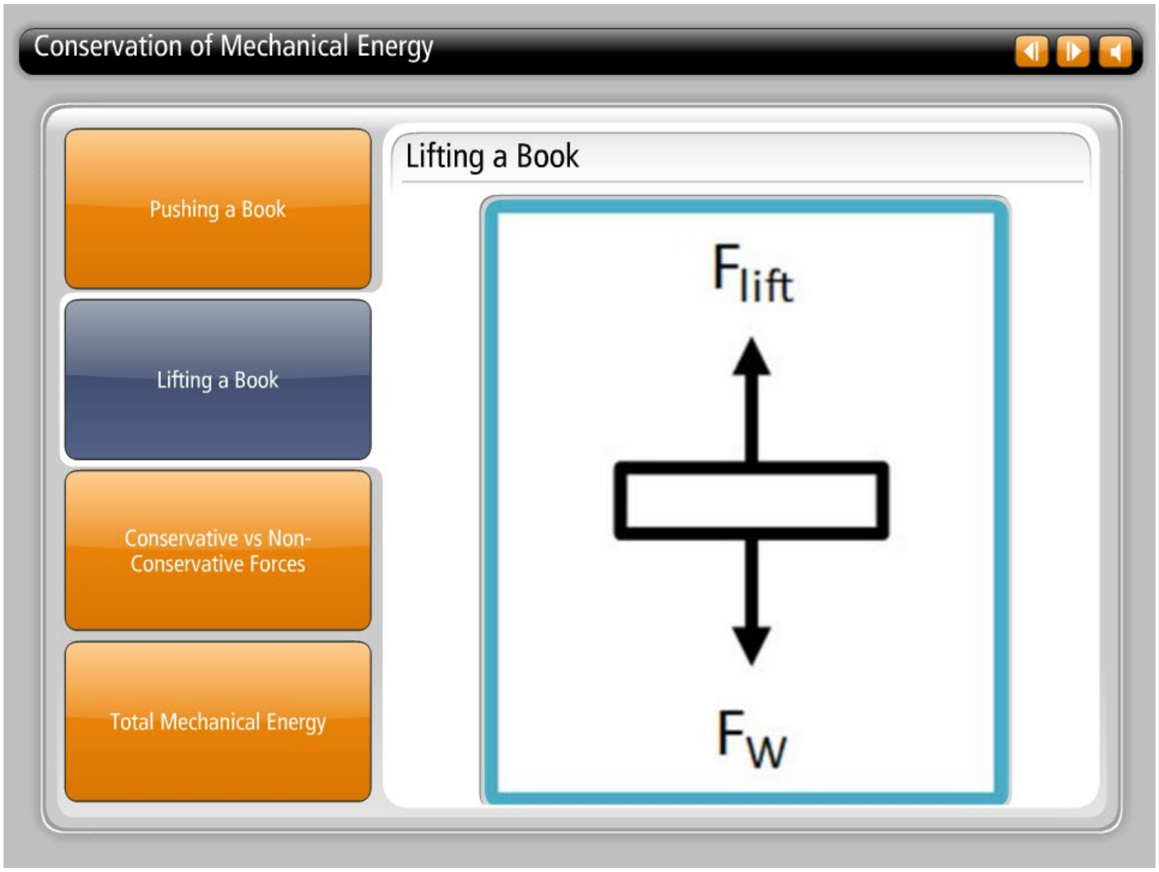
Topic 4 Content: Conservation of Mechanical Energy Presentation Notes



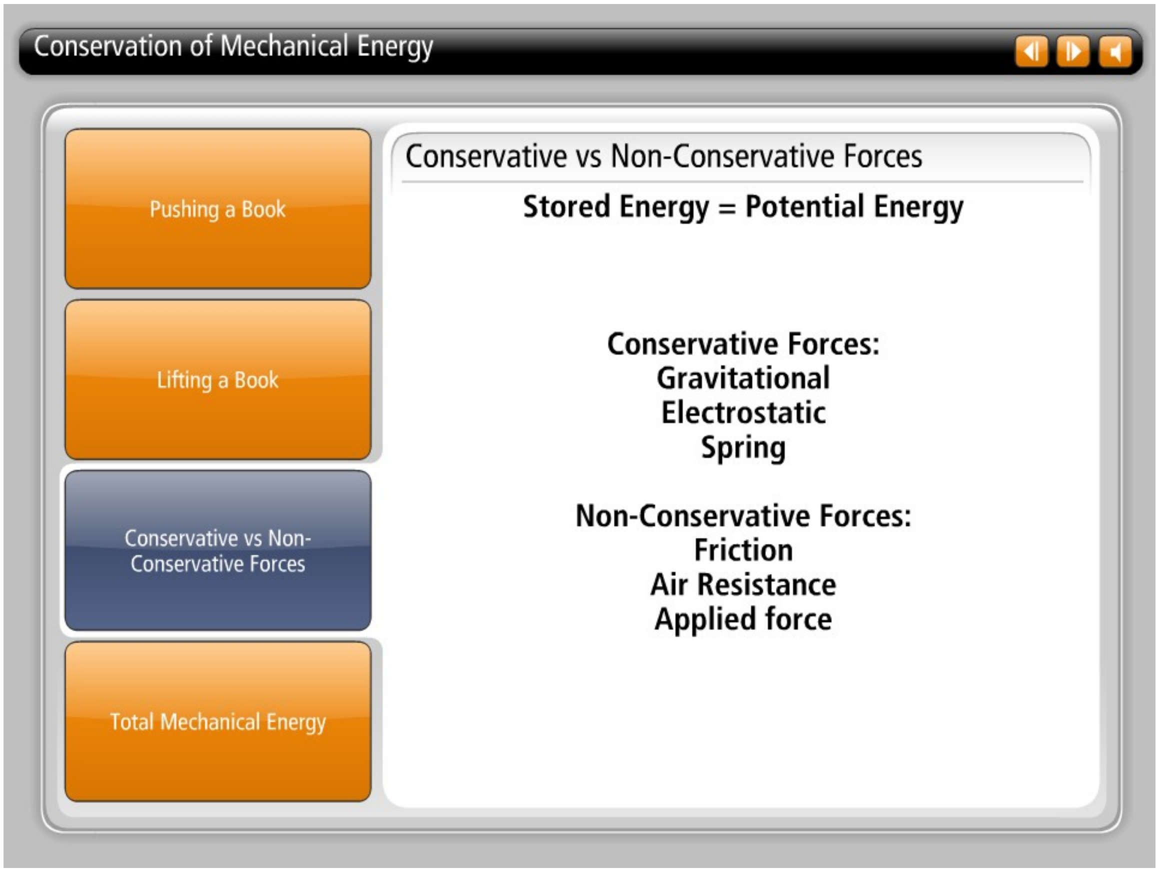
Earlier, you saw how work done by the net force changes the kinetic energy of an object. In this topic, you will take a different look at forces, work and energy to introduce another valuable tool in solving physics problems. To begin, you will take a look at two different situations: Pushing a book and lifting a book.



When you push a book along the table, you are applying a force in the direction of motion. At the same time, friction is applying a force opposite the direction of motion. You are doing work and friction is doing negative work and overall, no work gets done. When you let go of the book, you expect it to just stay there.



When lifting a book, you are applying a force in the direction of motion. At the same time, gravity is applying a force opposite the direction of motion. You are doing work and gravity is doing negative work and overall, no work gets done. When you let go of the book, however, it will accelerate towards the ground.

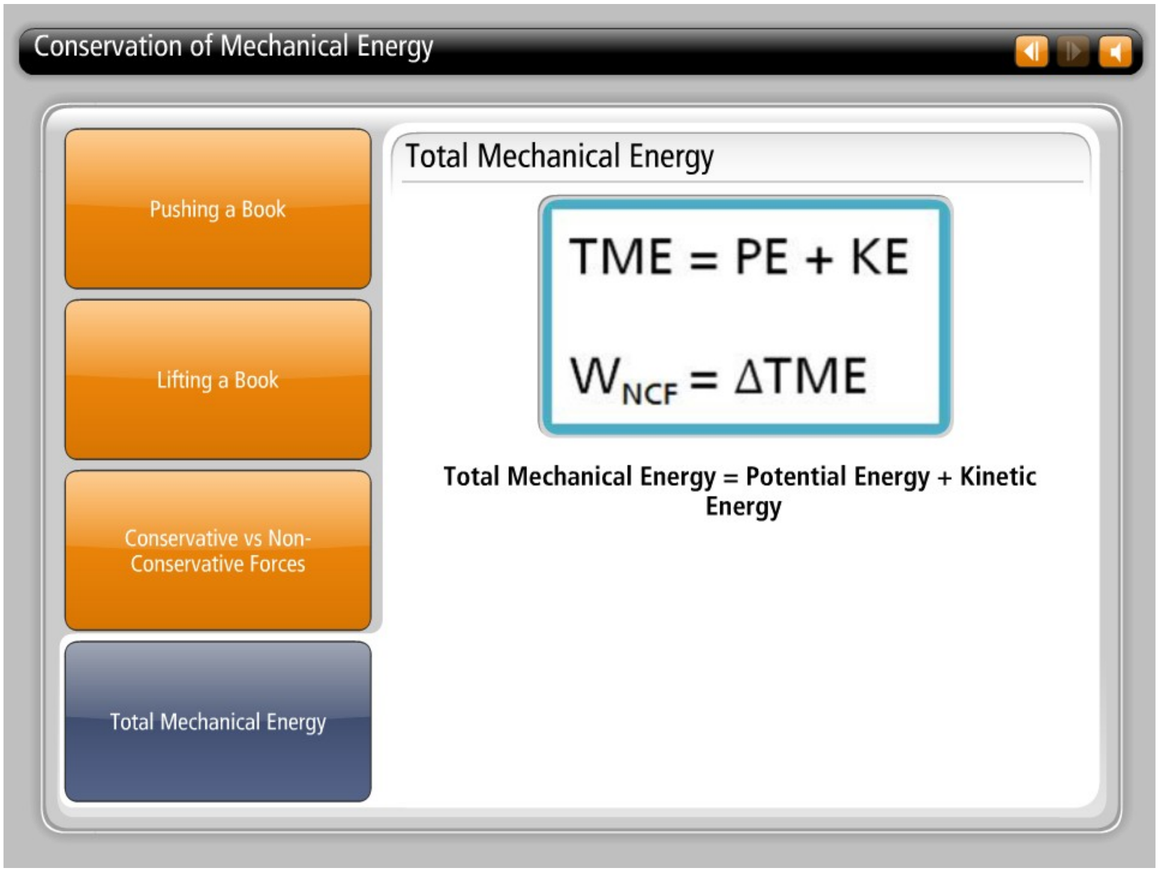


This points out a key distinction between different types of forces. Gravity is different because work done against gravity somehow gets stored up for later use, while work done against friction is lost to the surroundings in the form of heat. When work gets stored for later use, it is considered potential energy.

Gravity is called a conservative force and Friction is called a non-conservative force.

Other examples of conservative forces are the electrostatic force and the spring force.

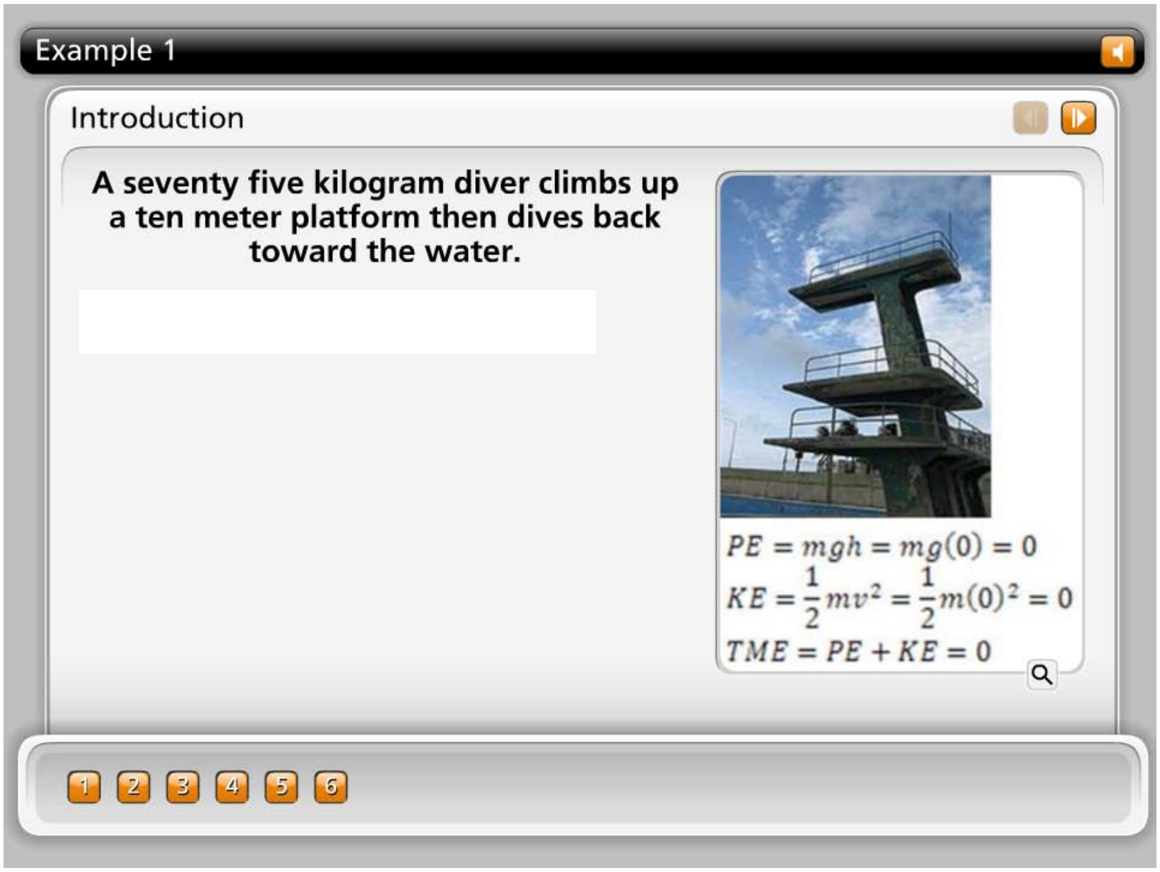
Non-conservative forces include friction, air resistance and most applied forces.



You now can define total mechanical energy as the sum of potential energy and kinetic energy.

Work done by non-conservative forces changes total mechanical energy. Work done by conservative forces does not change total mechanical energy, but merely transforms energy between potential and kinetic forms.

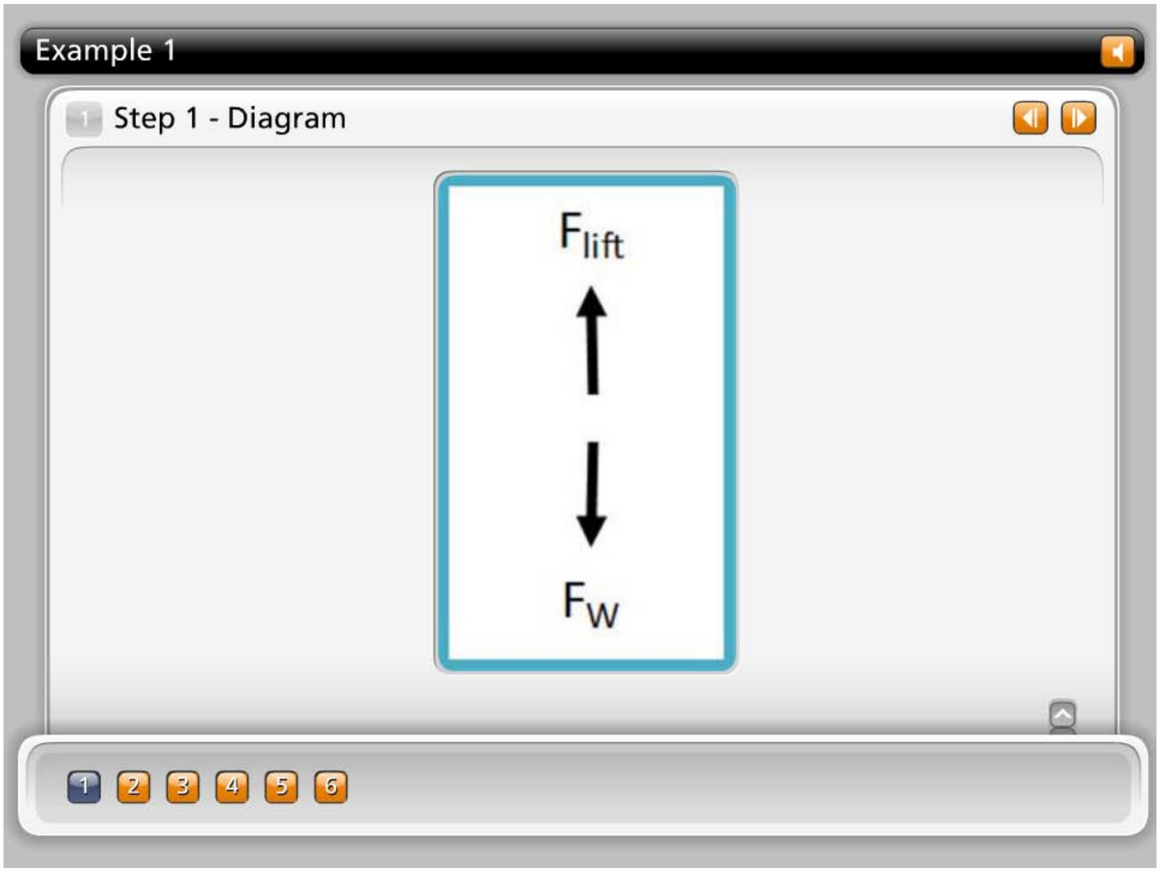
When only conservative forces are involved, you say that mechanical energy is conserved. The total quantity of mechanical energy remains the same.



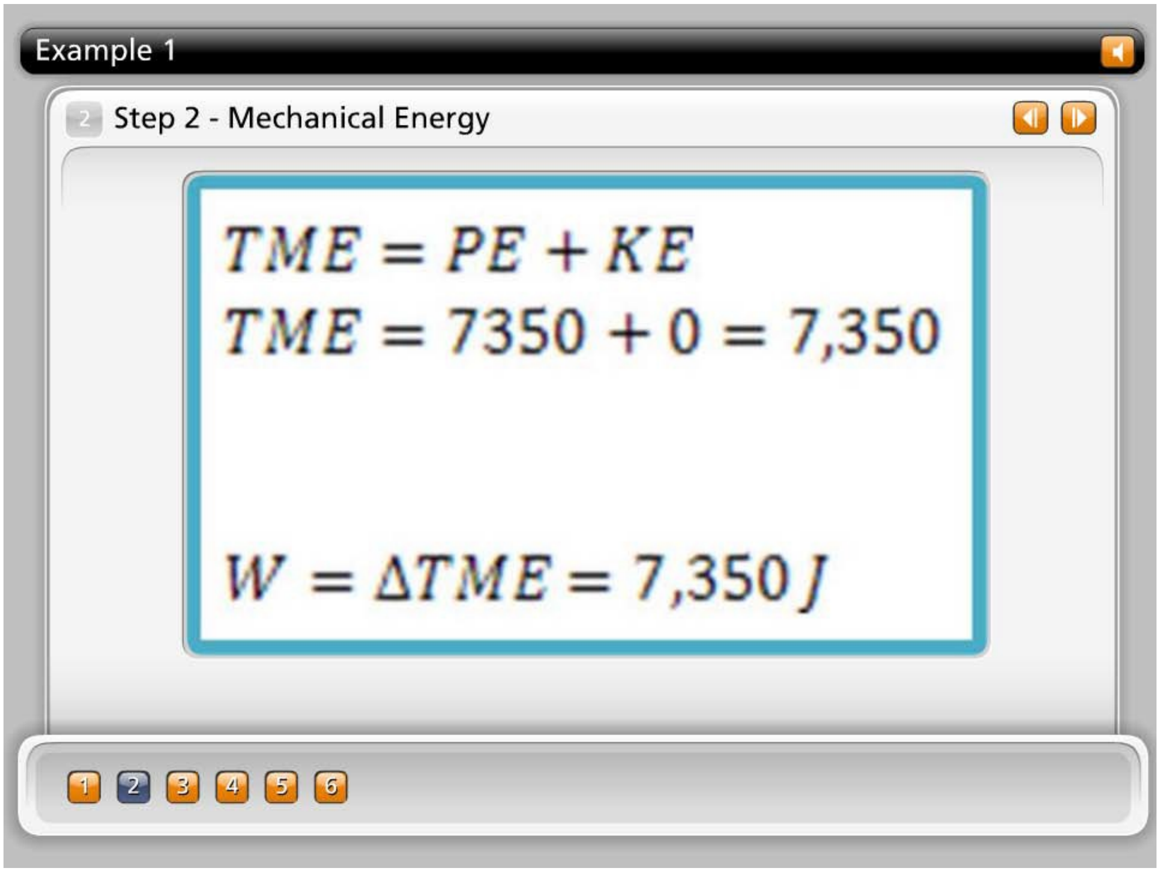
As our first example, let's look at a seventy five kilogram diver through the process of climbing up a ten meter platform then diving back toward the water.

The diver starts at rest at the bottom of the ladder. You will define this as zero height.

At this point, the diver has no potential energy, since he is at zero height, and also no kinetic energy since he is at rest. His total mechanical energy is zero.



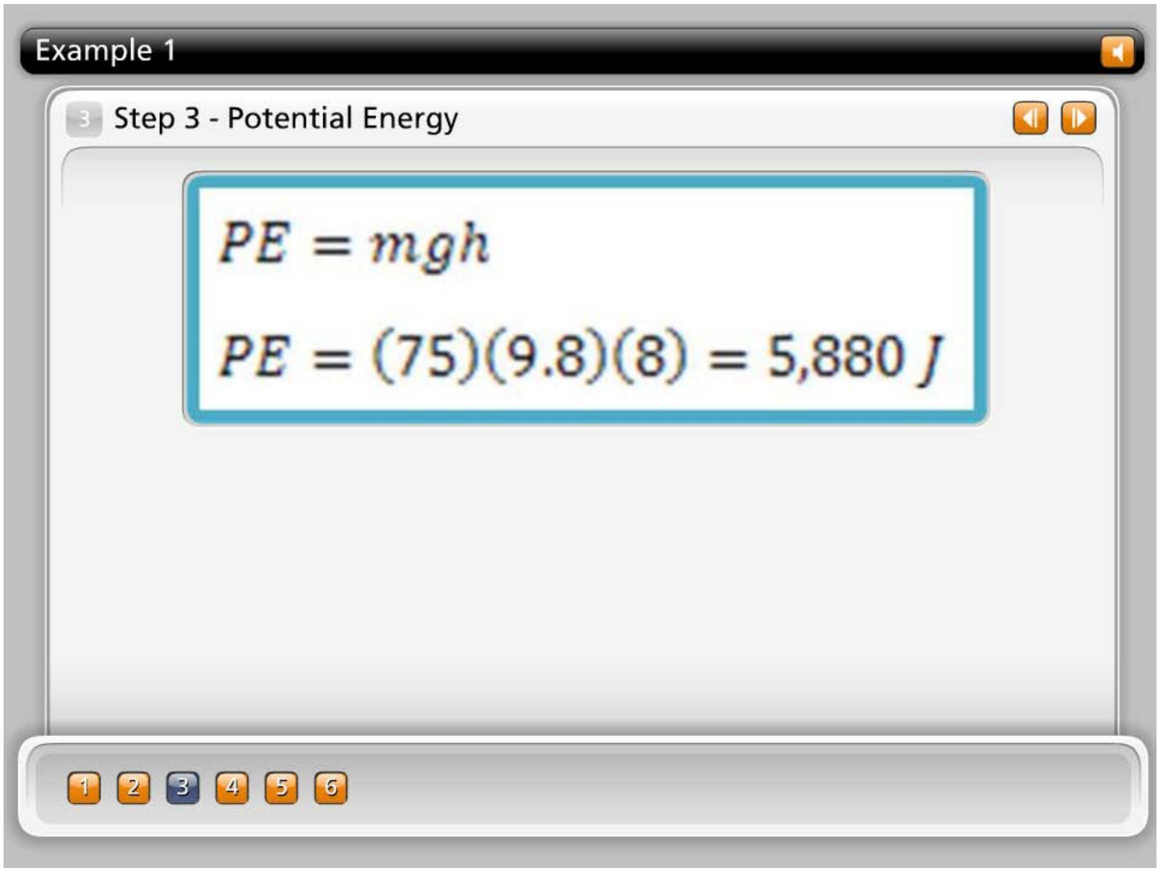
As the diver climbs the ladder, he does work lifting himself against the force of gravity. Chemical energy within his body is being converted to potential energy and heat as he climbs. He is applying a non-conservative force, so is increasing the total amount of mechanical energy. The gravitational force is a conservative force, so it does not affect the amount of mechanical energy.



Reaching the top of the platform, the diver is once again at rest. His kinetic energy is zero. But now, ten meters high, he has potential energy. This can be calculated using the equation potential energy equals mass times the acceleration of gravity times height. You see that his potential energy is now equal to seven thousand three hundred fifty Joules.

His mechanical energy at this point is equal to his kinetic plus his potential energy and is equal to seven thousand three hundred fifty Joules.

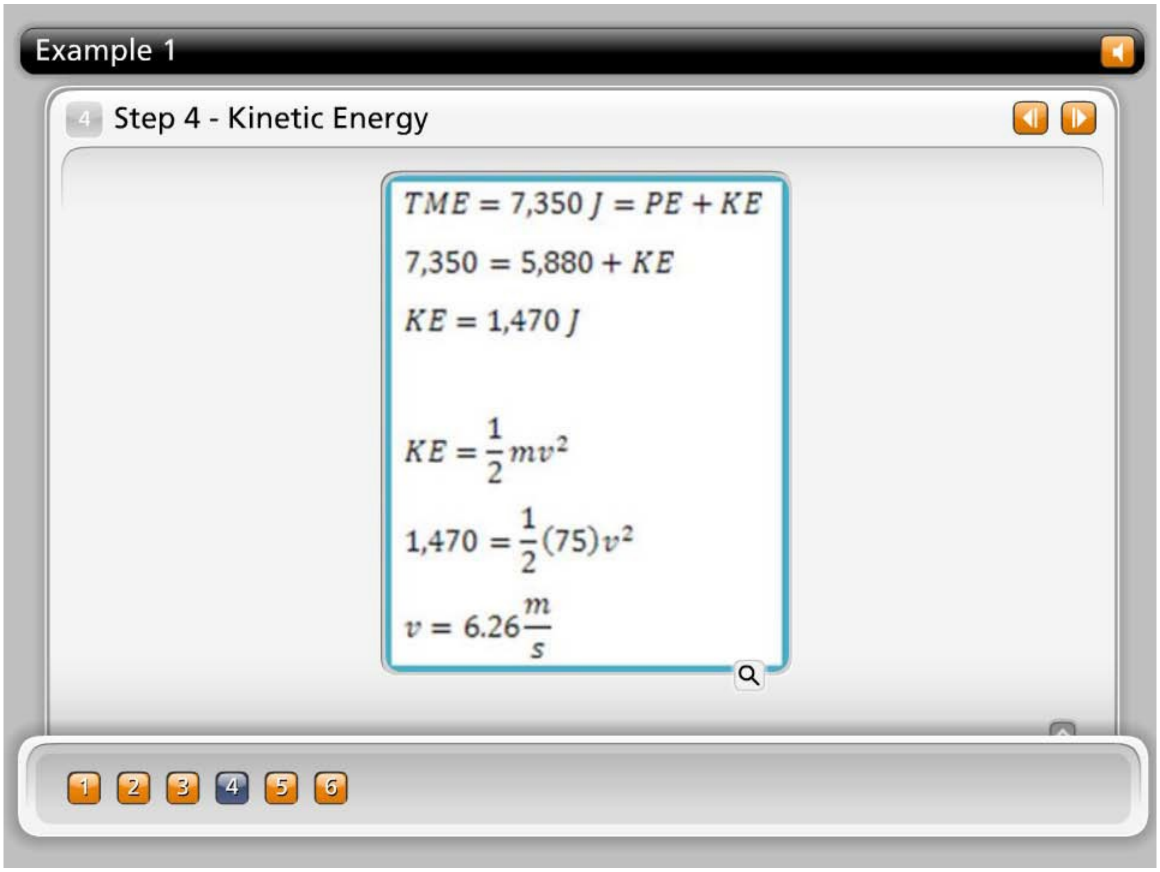
This is the amount of work that the diver did climbing the tower. The work he did is equal to the change in mechanical energy.



Now, starting from rest, the diver falls from the tower towards the water below.

As he falls, mechanical energy is conserved. The gravitational force is doing work to him, but since it is a conservative force, it does not change his mechanical energy. Instead, his potential energy decreases as his kinetic energy increases, but the two will always add up to the same total mechanical energy.

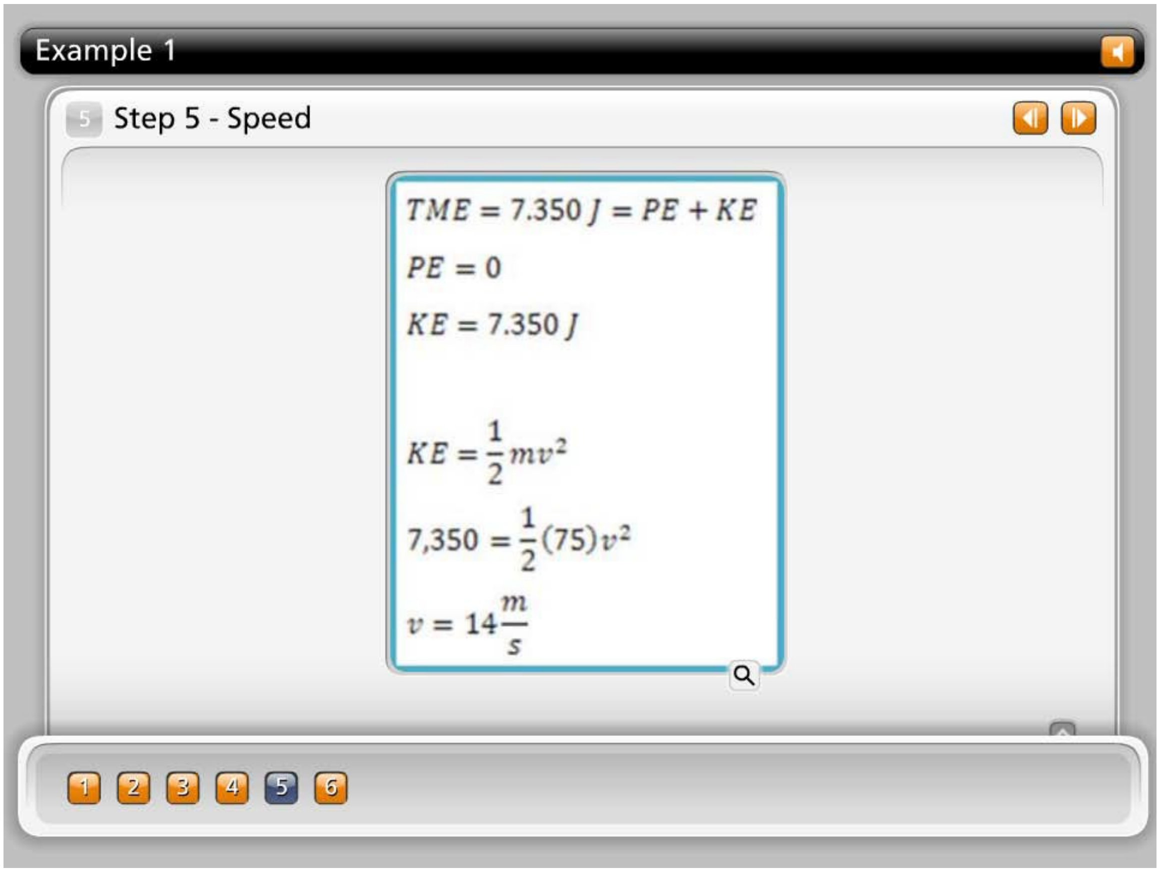
As he passes eight meters, you can calculate his potential energy. Using our equation for potential energy you see that his potential energy is now five thousand eight hundred eighty Joules. Since his total mechanical energy remains seven thousand three hundred fifty Joules, you can calculate his kinetic energy at this point.



Subtracting potential energy from total mechanical energy, you find that his kinetic energy at this point is now one thousand four hundred seventy Joules.

From this, you are now able to calculate his current speed.

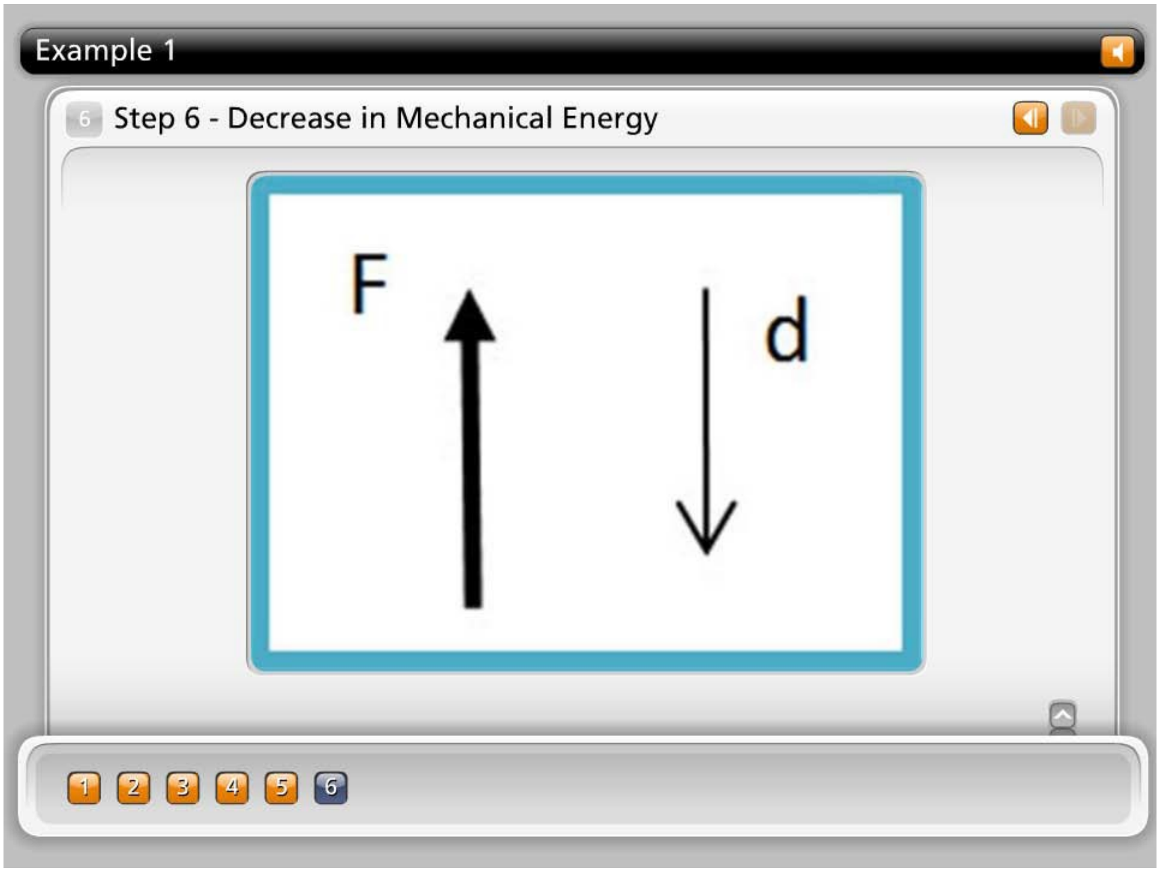
Using our equation for kinetic energy, you see that his speed is now six point two six meters per second.



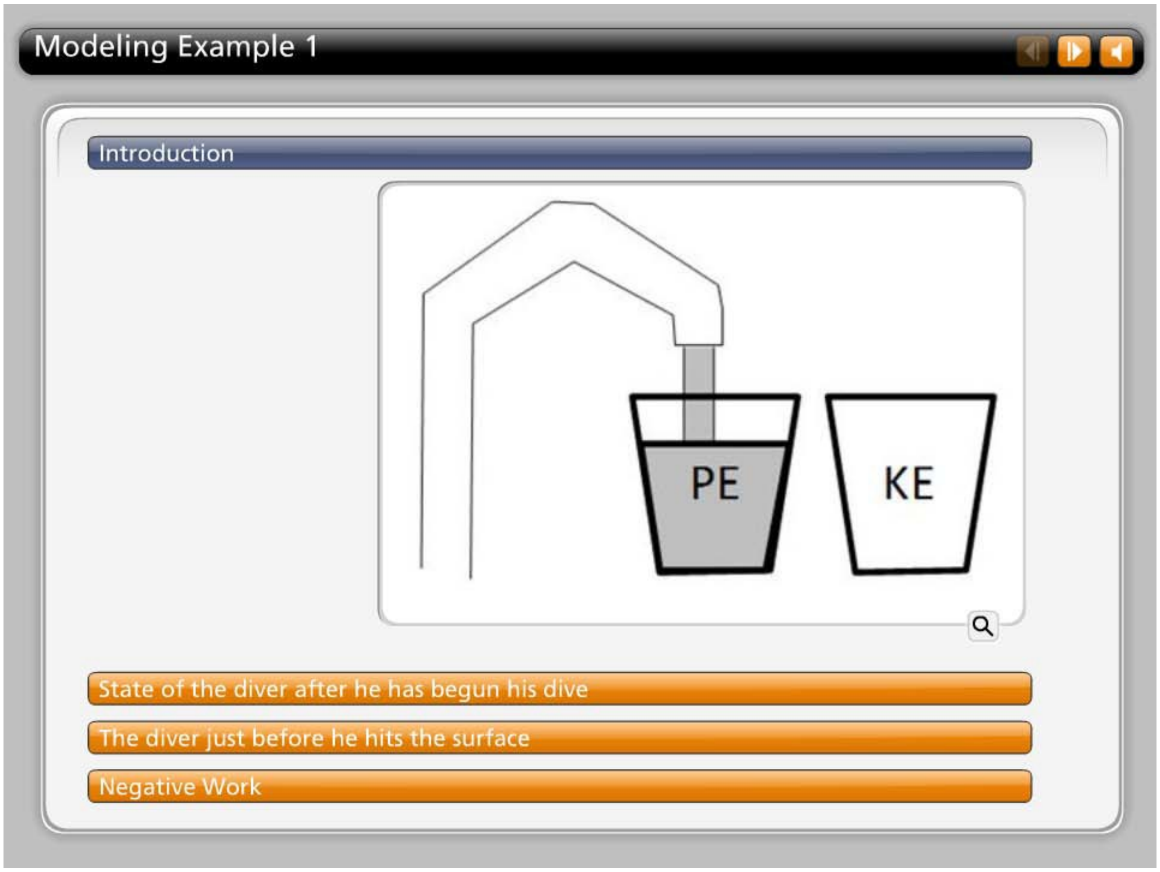
You will also calculate his speed immediately before he hits the water.

Here, he still has the same total mechanical energy of seven thousand three hundred fifty Joules. But now he is at zero height so his potential energy is zero. This means that his kinetic energy is equal to his total energy.

Once again, using our kinetic energy equation you see that his speed immediately before he hits the water is fourteen meters per second.

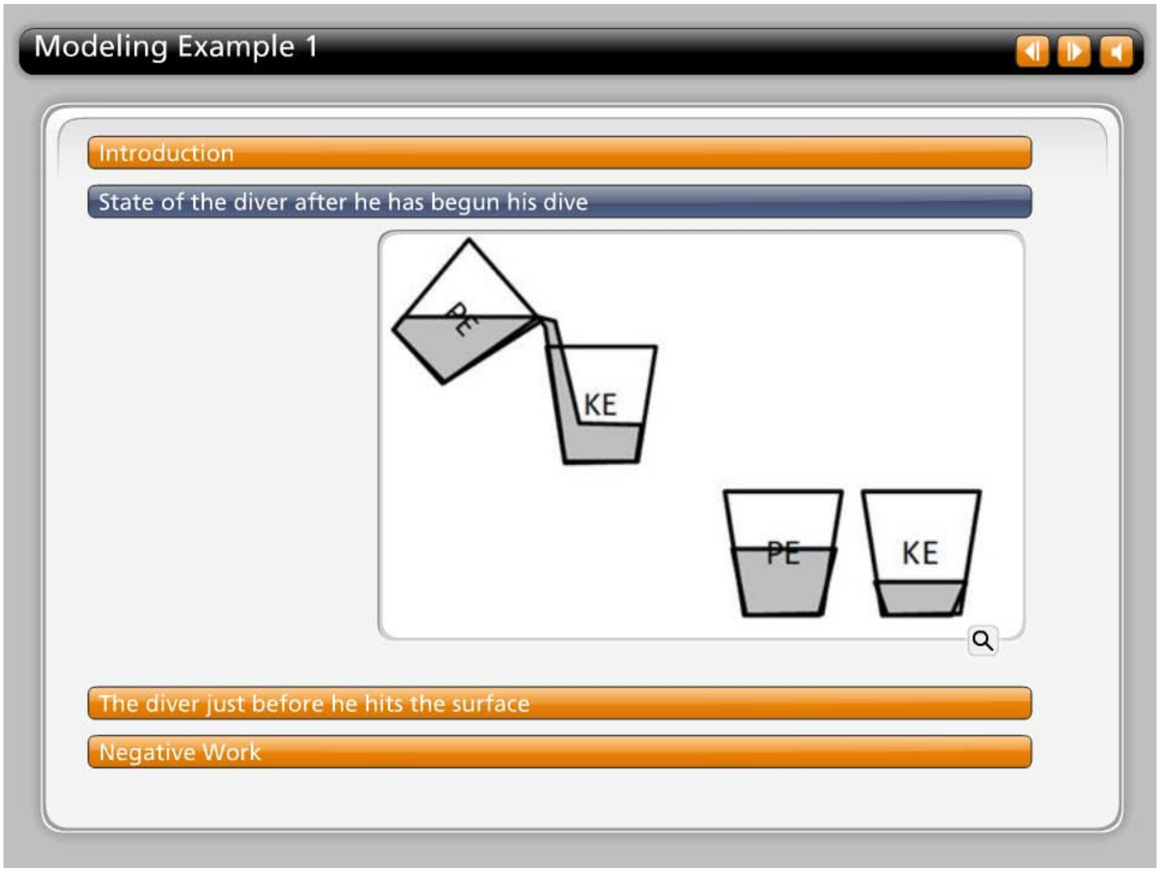


Once the diver hits the water, the resisting force of the water, a non-conservative force, acts against his motion. This slows him down, doing negative work on him and decreasing his mechanical energy.



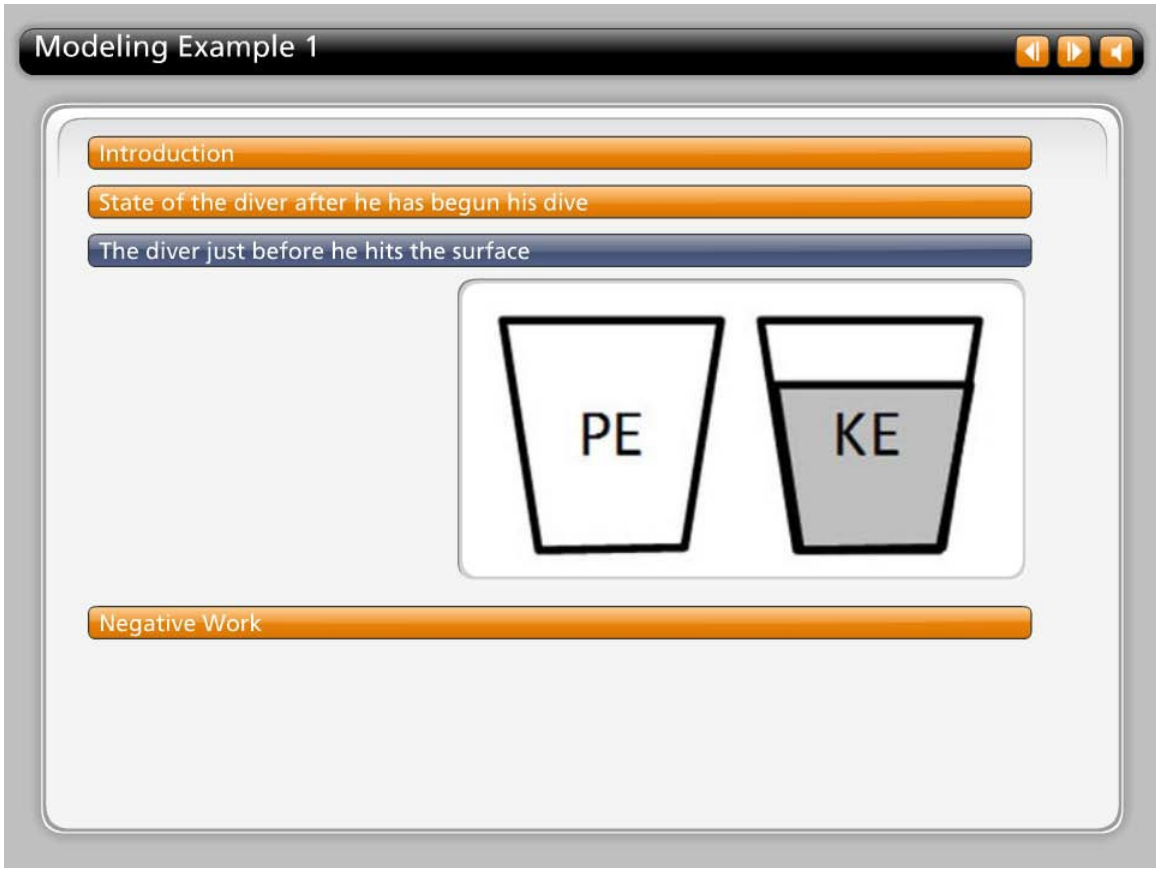
To better understand this concept, you will model it using household objects.

Take two plastic cups. Label one P E and the other K E. Stand by a sink and slowly fill the P E cup with water. The water represents mechanical energy, and the faucet represents positive work being done by a non-conservative force. This is like the diver climbing the ladder.



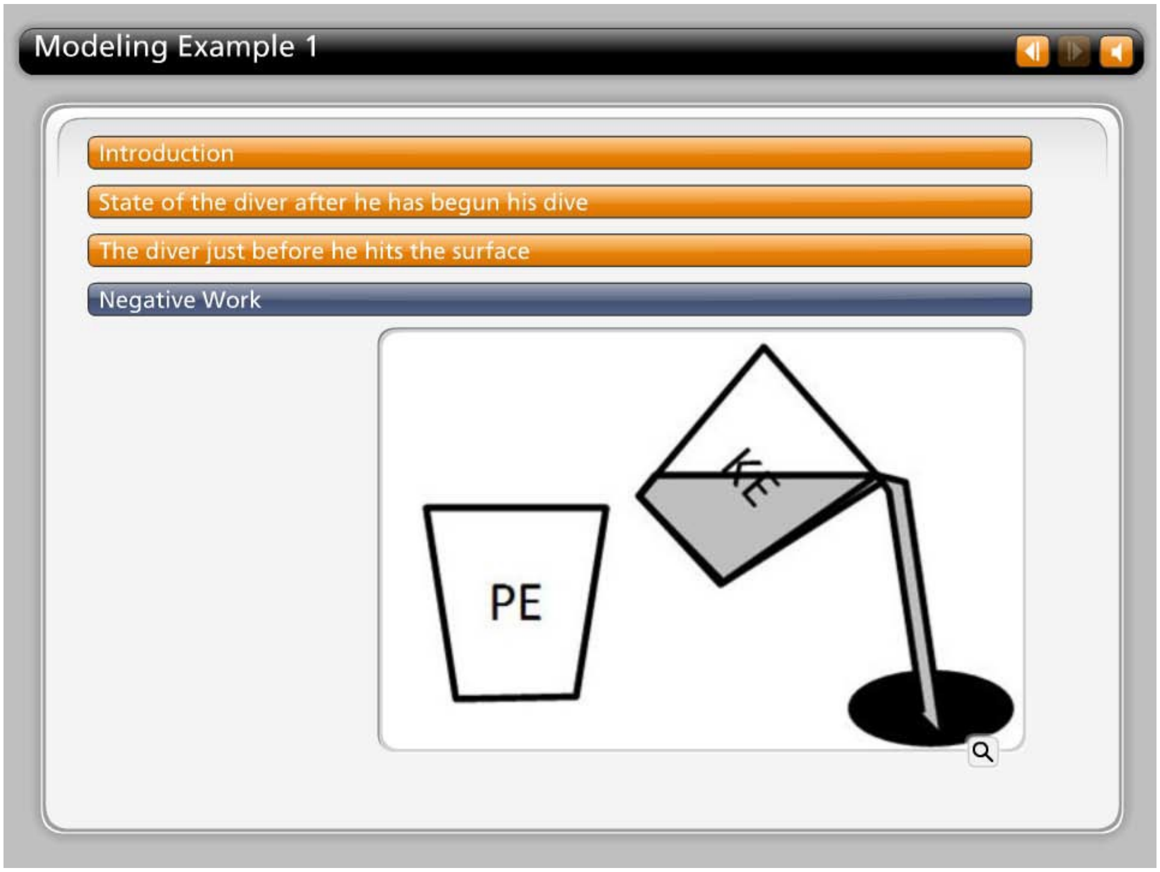
Now slowly pour some of the water from the cup labeled P E to the cup labeled K E. This represents the state of the diver after he has begun his dive. The amount of water that leaves one cup is equal to the amount of water that enters the other, but the total amount of water remains the same. Just as the amount of potential energy that the diver loses is equal to the amount of kinetic energy the diver gains, but the total amount of mechanical energy remains constant.

This transformation happens as the conservative force of gravity acts on the diver.



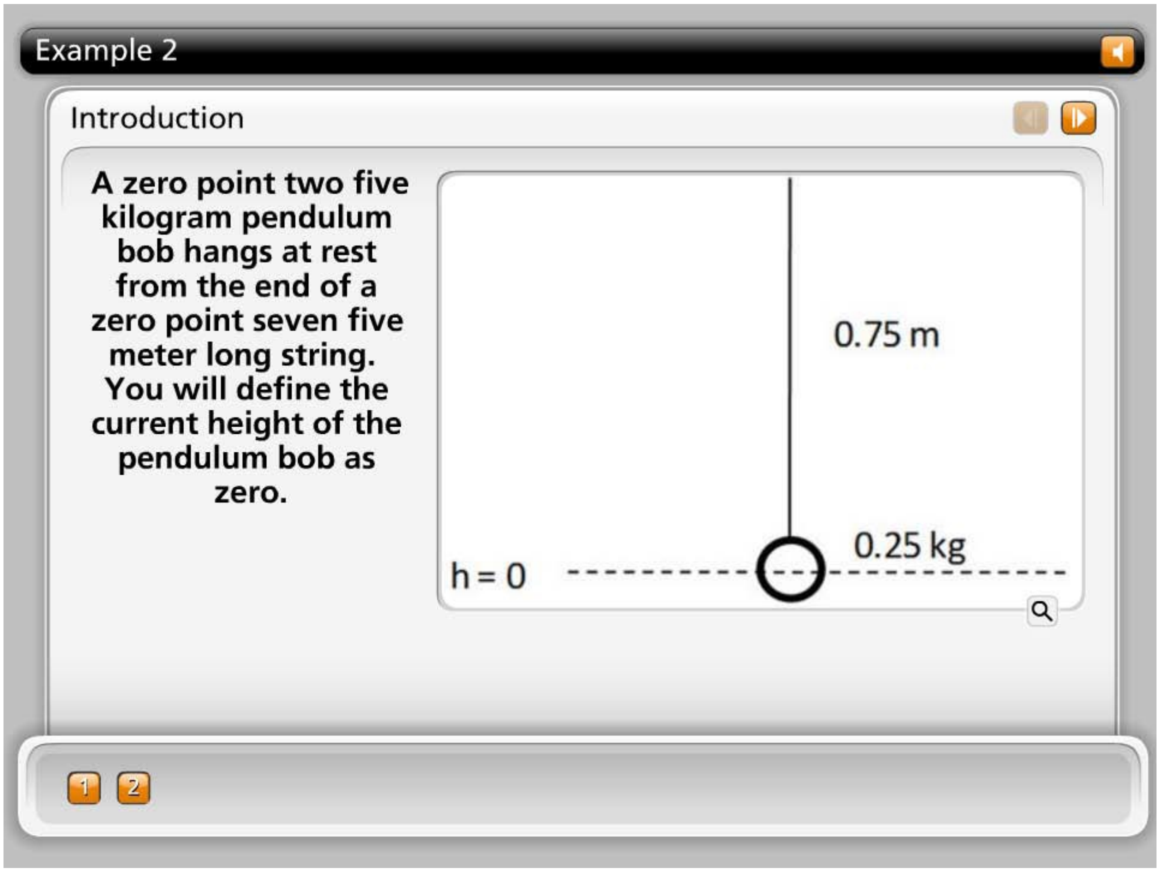
Pour the rest of the water from the cup labeled P E to the cup labeled K E. This represents the diver just before he hits the surface.

The total amount of water remains constant, just as the total amount of energy remains constant, but now it is all in the form of KE.



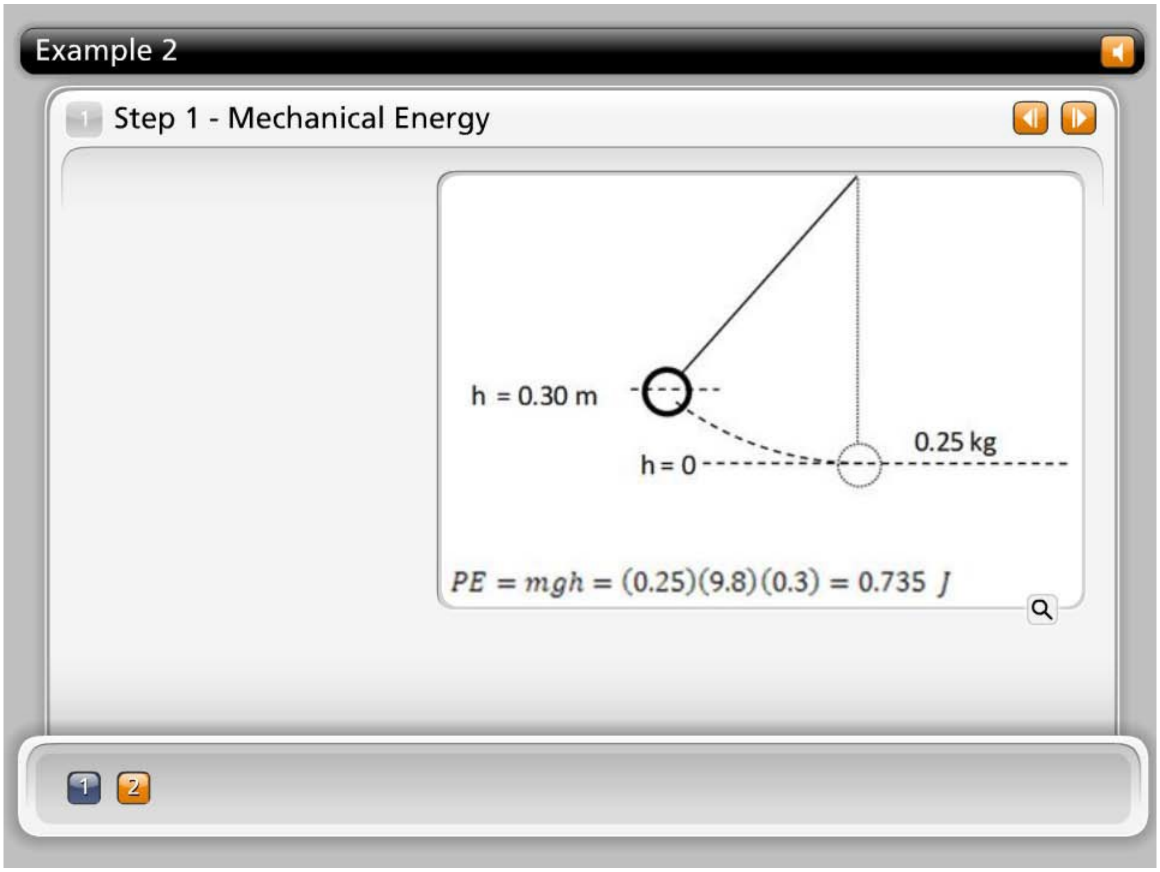
Finally, pour the water down the drain. The drain represents negative work done by the non-conservative force of friction.

It will be useful to return to this model as you think about conservation of energy.



As another example of conservation of energy, let's look at a pendulum. A zero point two five kilogram pendulum bob hangs at rest from the end of a zero point seven five meter long string. You will define the current height of the pendulum bob as zero.

At this point, the pendulum is not moving, so it has no kinetic energy. It is also at zero height, so it has no gravitational potential energy.

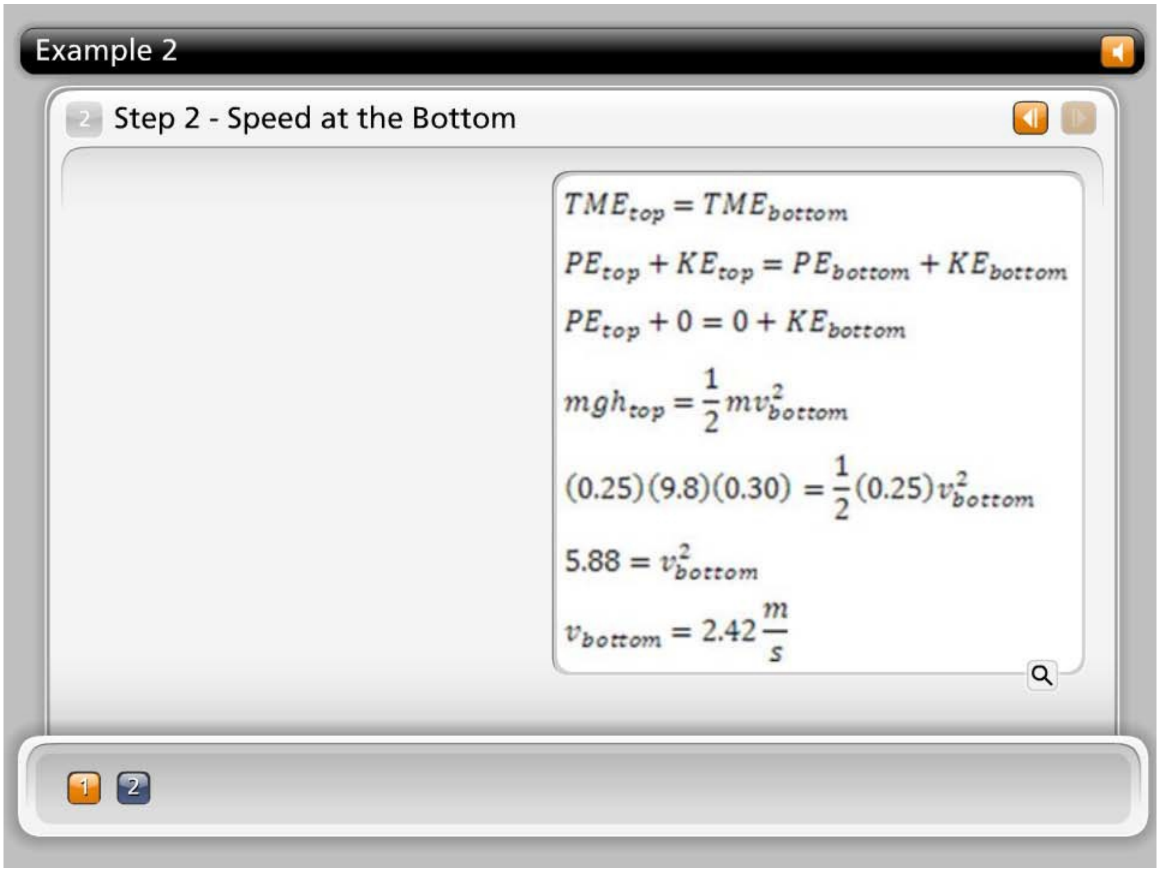


Now, you will do some work on the pendulum by lifting the pendulum bob up to a height of zero point three zero meters. The pendulum is again at rest, so the kinetic energy is zero. But now the pendulum bob has obtained potential energy from the work that was done by the non-conservative lifting force. The work done is related to the new height of the pendulum bob, not the path it took to reach that height. Since kinetic energy is zero, the mechanical energy is simply equal to the potential energy. Calculating, you see that the total energy is now zero point seven three five Joules.

Zero point seven three five Joules of work was done to the pendulum by a non-conservative force, and it now contains zero point seven three five Joules of mechanical energy.

You now will release the pendulum bob. At this point, ignoring friction, no work is being done to the bob as it swings back and forth.

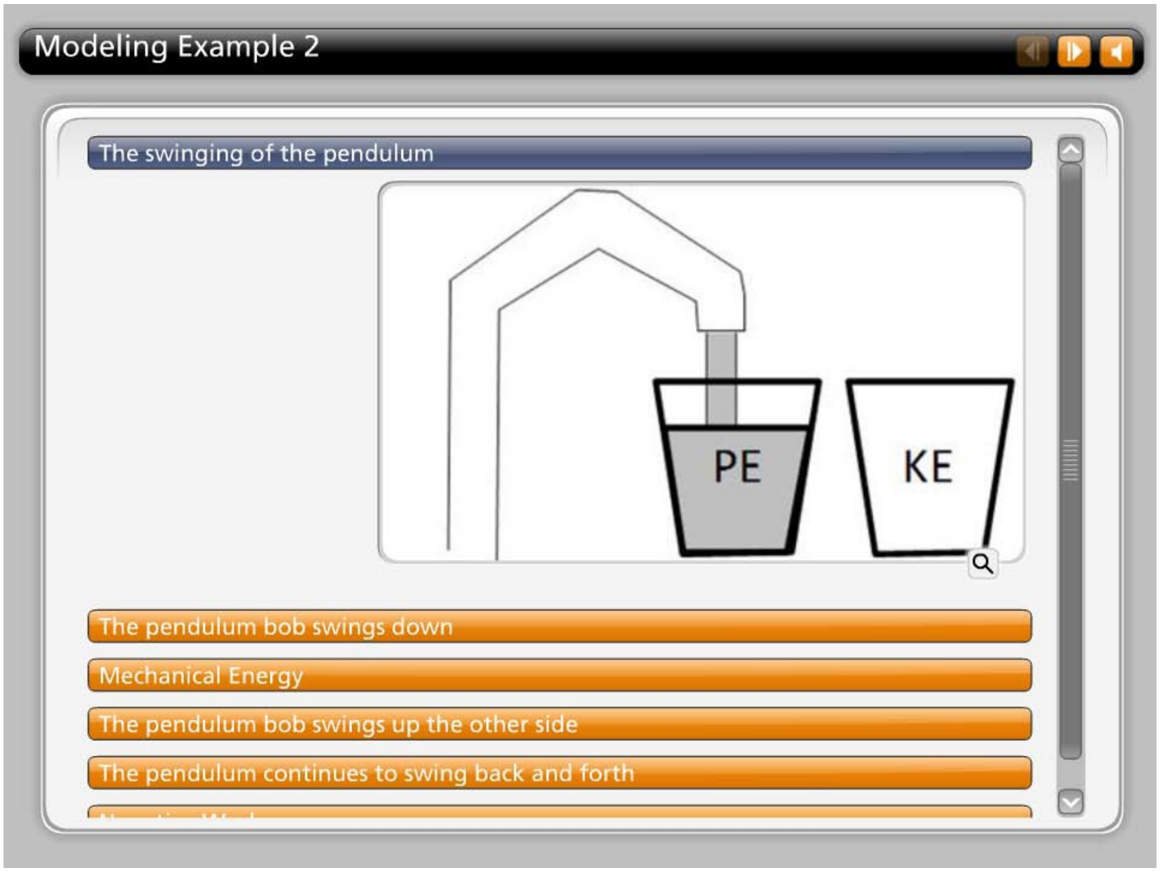
The string of the pendulum always applies a force perpendicular to the motion and therefore does no work on the pendulum bob. The gravitational force is acting on the bob, converting potential to kinetic energy, but the gravitational force is a conservative force, so it does not change total mechanical energy.



As the pendulum bob swings back down to its lowest position, the potential energy decreases as it is transformed into kinetic energy of the moving bob. What is the speed of the pendulum bob at its lowest point?

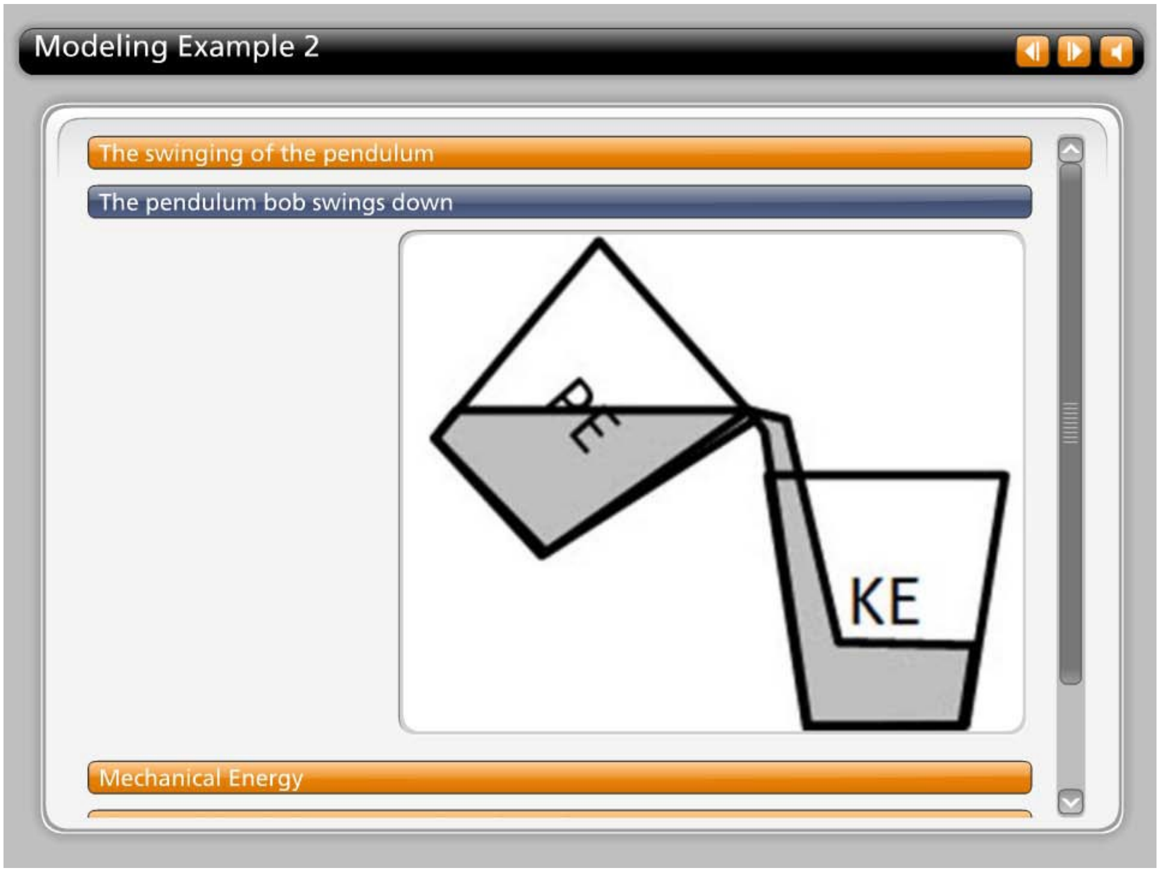
Since no work is being done, you know that the total mechanical energy is constant. So potential energy at the top plus kinetic energy at the top equals potential energy at the bottom plus kinetic energy at the bottom.

Since the pendulum bob is at rest at the top of its swing and is at zero height at the bottom of its swing, you can set the potential energy at the top equal to the kinetic energy at the bottom. Expanding the equations and substituting our values you find that the speed at the bottom is equal to two point four two meters per second.



You can again model the swinging of the pendulum with our cups of water.

The work done lifting the pendulum adds potential energy. This is represented by filling the PE cup from the faucet.



As the pendulum bob swings down, potential energy is converted to kinetic energy.

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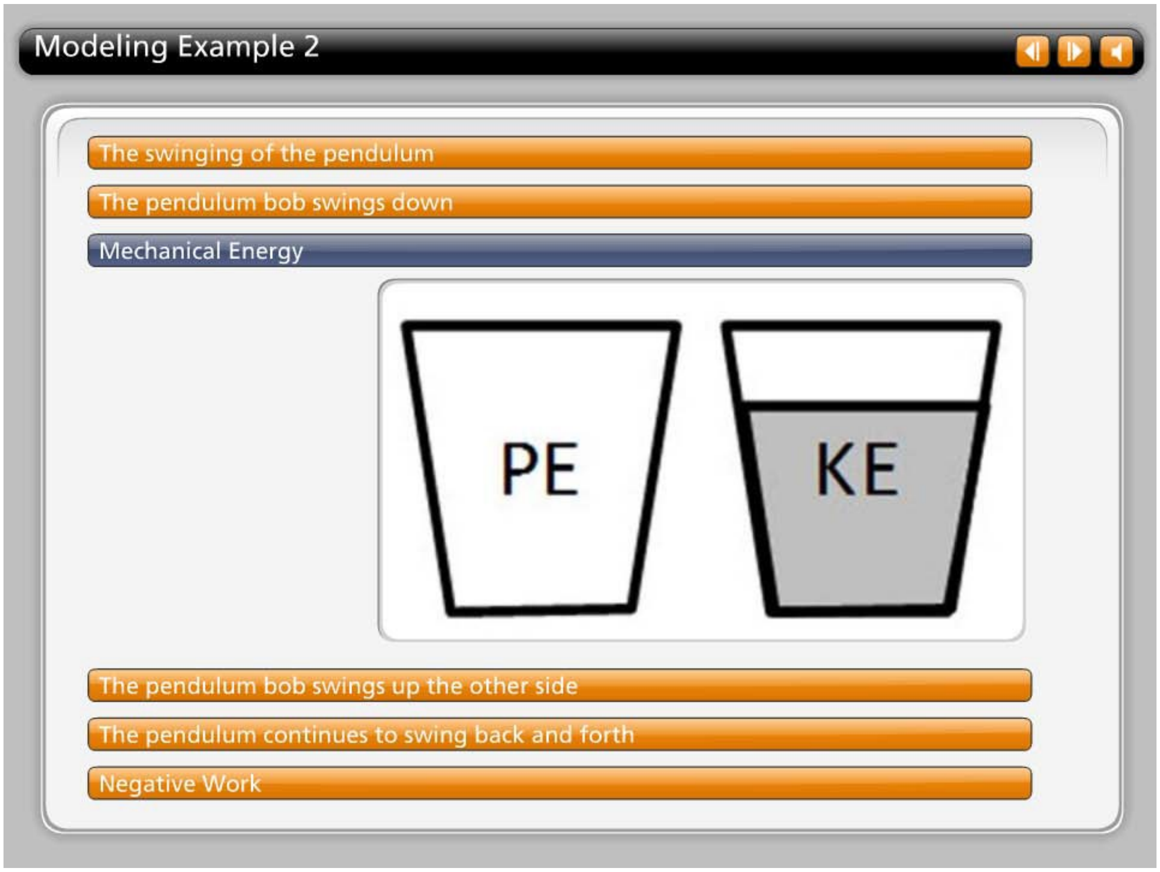
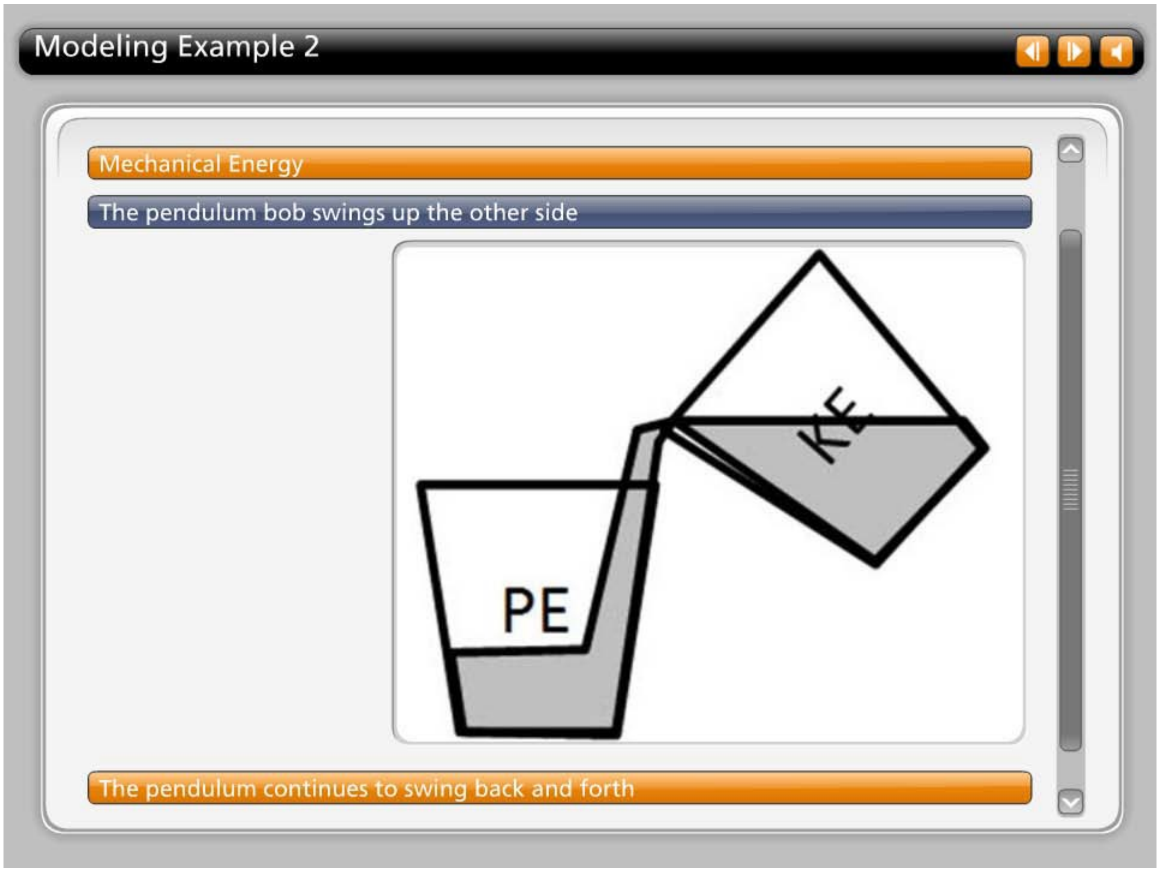


At the lowest point, you have no potential and all kinetic energy, however, the total amount of mechanical energy remains the same.



As the pendulum bob swings up the other side, the kinetic energy transforms back into potential energy, with the total amount of mechanical energy remaining constant.

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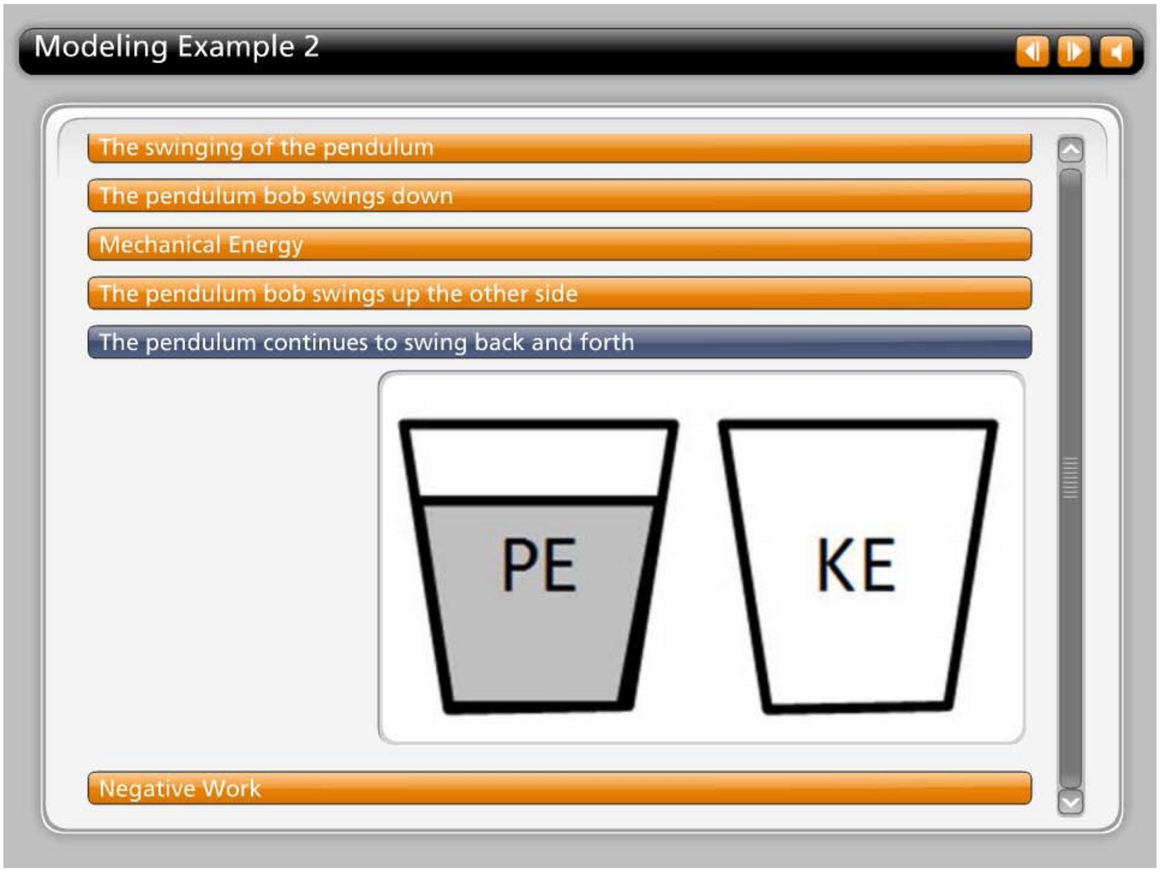
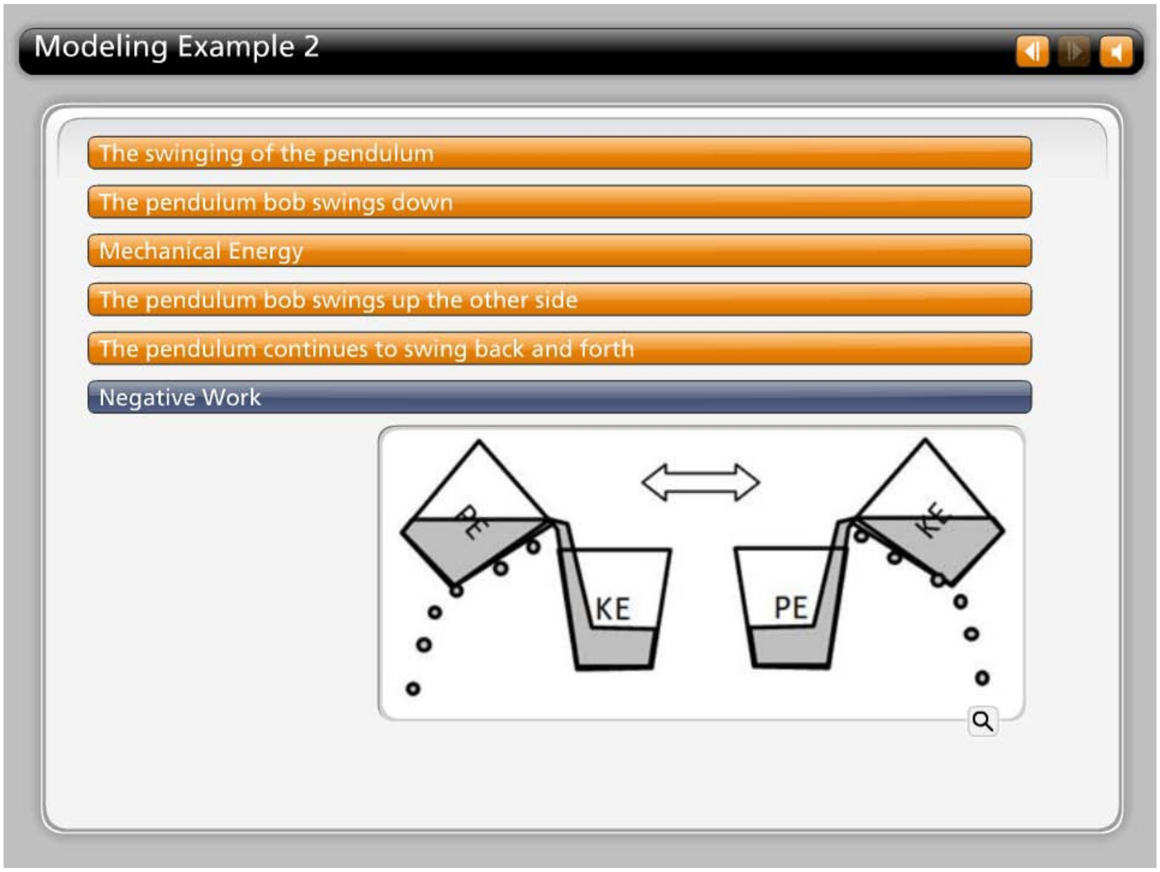


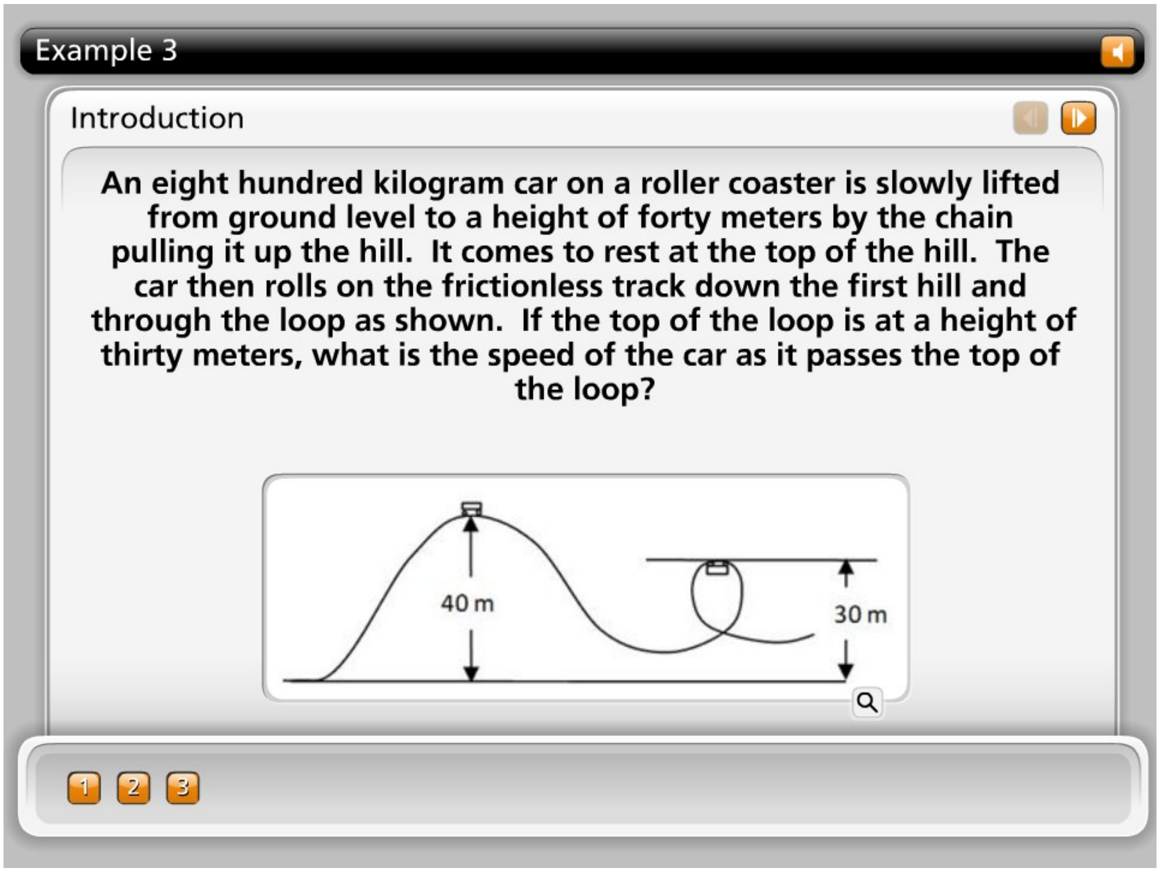
At the top of the path on the other side, you have once again returned to all potential and no kinetic energy as the pendulum bob comes briefly to rest.

As the pendulum continues to swing back and forth, this process repeats, potential to kinetic to potential again.



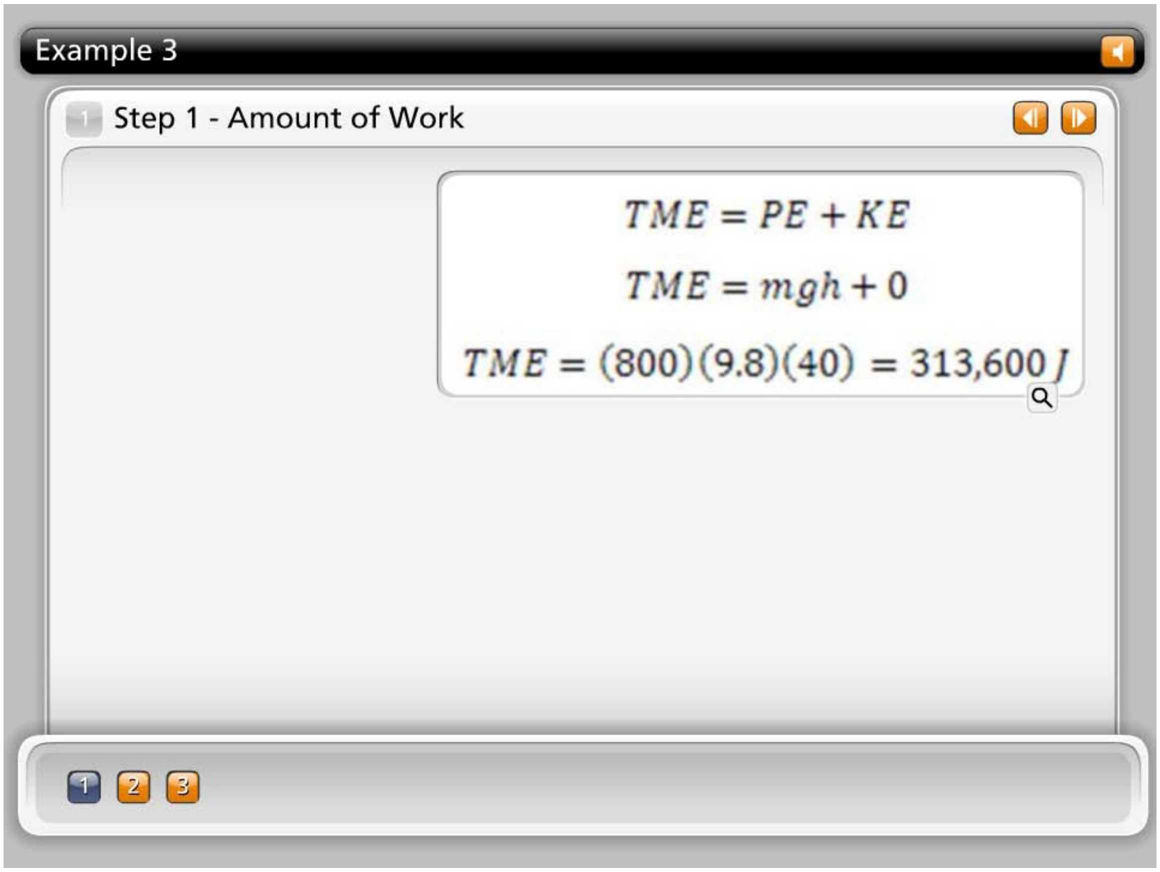
In reality, friction does negative work on the pendulum, slowly transforming the mechanical energy into thermal energy, slightly heating up the air and the pendulum bob itself. This can be modeled by splashing a small amount of water down the drain with each transfer.

As you know, no transfer of energy, mechanical or otherwise, is one hundred percent efficient. Some energy is always lost to the environment.



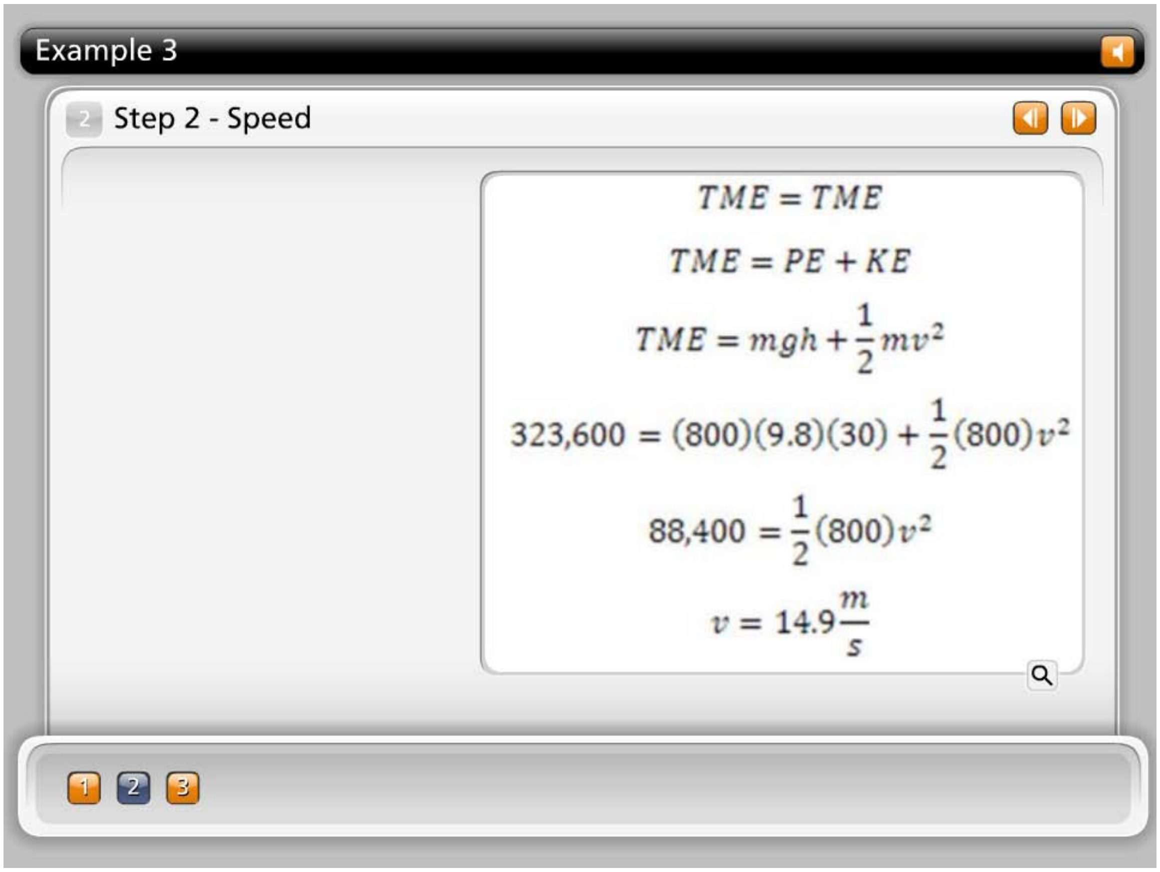
As a third example, you'll take a look at a roller coaster.

An eight hundred kilogram car on a roller coaster is slowly lifted from ground level to a height of forty meters by the chain pulling it up the hill. It comes to rest at the top of the hill. The car then rolls on the frictionless track down the first hill and through the loop as shown. If the top of the loop is at a height of thirty meters, what is the speed of the car as it passes the top of the loop?



The chain does work on the car lifting it up to a height of forty meters. The amount of work done is equal to the change of mechanical energy of the car. At the bottom of the hill, the car is at zero height and was not moving, so has no mechanical energy.

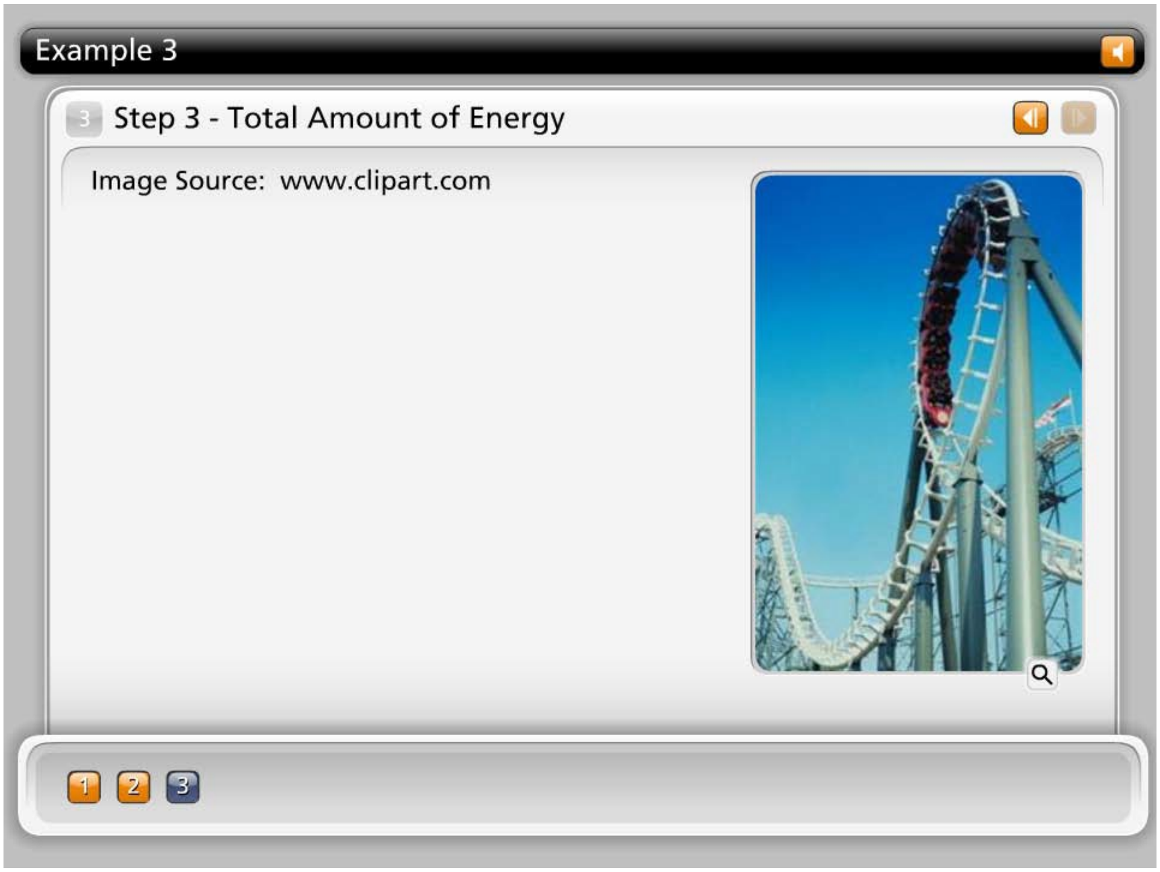
At the top of the hill, the car has potential energy, but it is at rest, so has no kinetic energy. The total mechanical energy of the car at the top of the hill is equal to m g h. Substituting the height of the hill and the mass of the car, you see that the mechanical energy at the top of the hill is three hundred thirteen thousand six hundred Joules. This is the amount of work the chain did lifting the car.



From this point, there is no work done on the car by non-conservative forces. Total mechanical energy is conserved. As the car goes down the hill, potential energy is transformed into kinetic energy. As it rises again to the top of the loop, some of the kinetic energy is transformed again to potential energy.

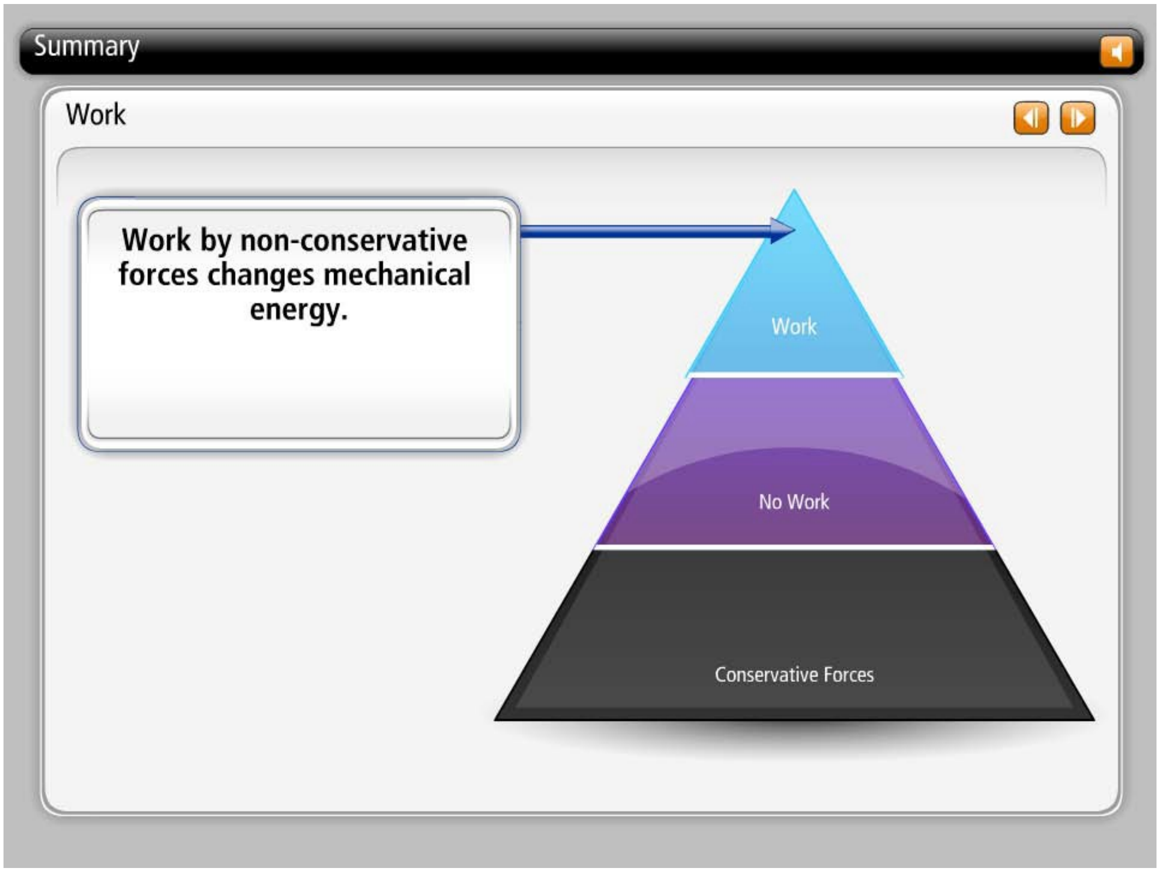
At the top of the loop, the car is moving, so it has kinetic energy, and it is above zero height, so it has potential energy. The sum of the potential energy and the kinetic energy will equal the total mechanical energy the car had at the top of the first hill.

Substituting our values and solving, you see that the car has a speed of fourteen point nine meters per second as it passes through the top of the loop.

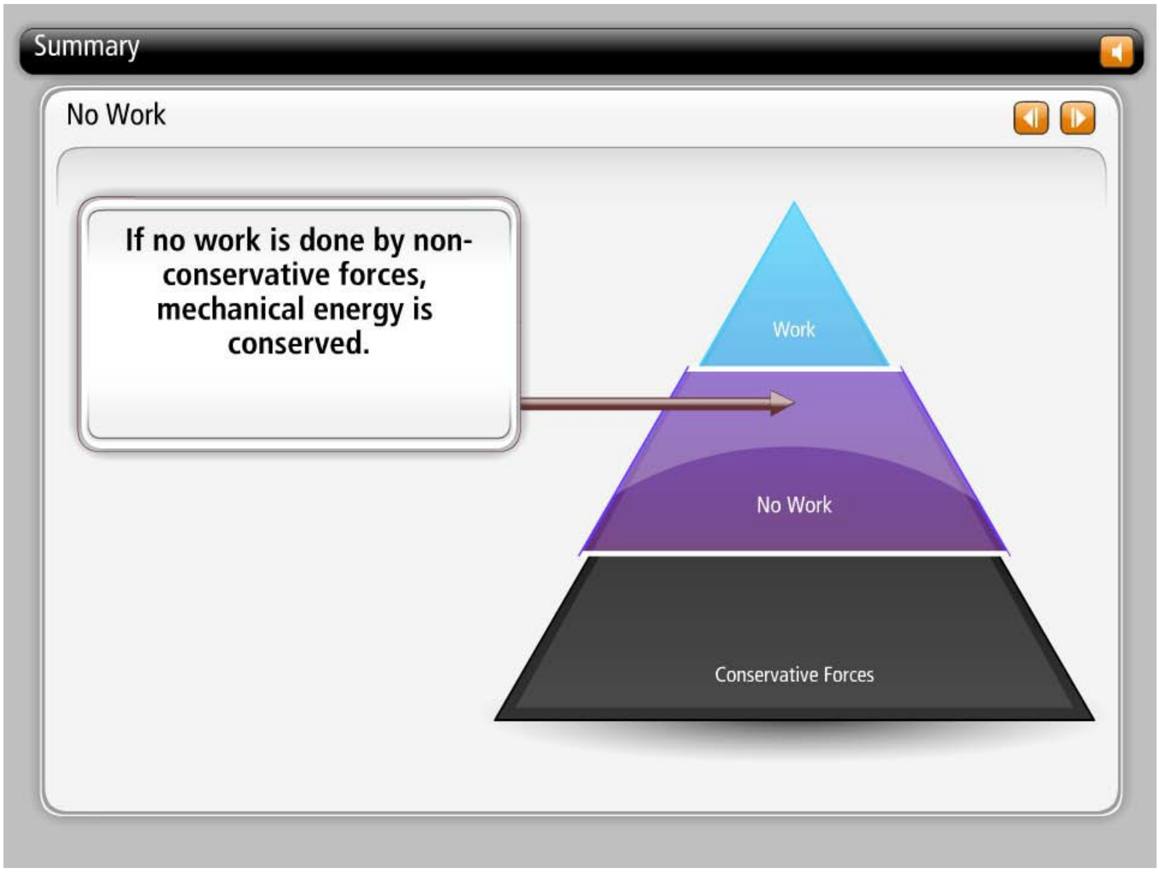


Again, you can apply the analogy of the cups and water. The chain does work to the car lifting it up as the P E cup fills with water.

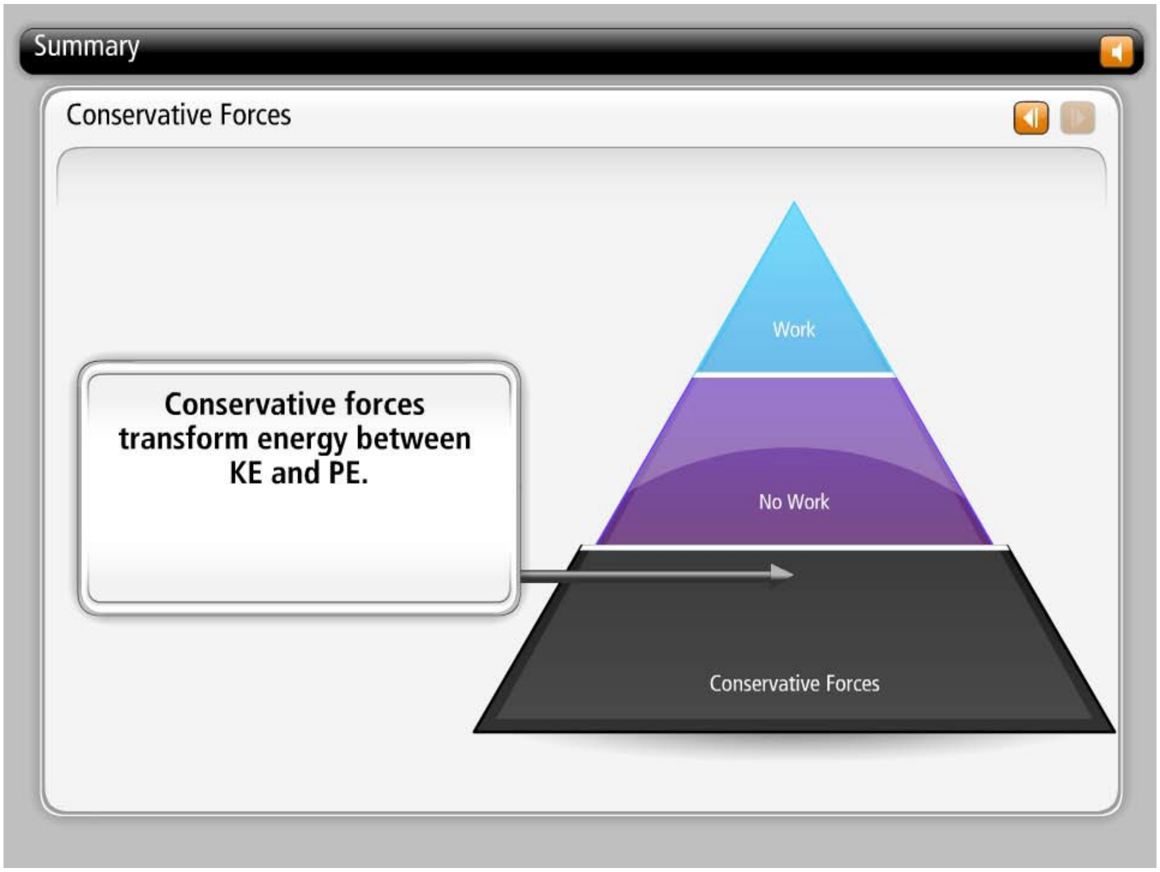
As the car rolls down the first hill, some P E is transformed to K E, then K E is transformed back to P E as the car rolls into the loop. The total amount of energy throughout these transformations remains constant.



As you can see, conservation of energy is a powerful tool for analyzing motion. Work done on a system by non-conservative forces changes the mechanical energy of the system.



If no work is done by non-conservative forces, mechanical energy is conserved.



Conservative forces act to transform energy between kinetic energy and potential energy.