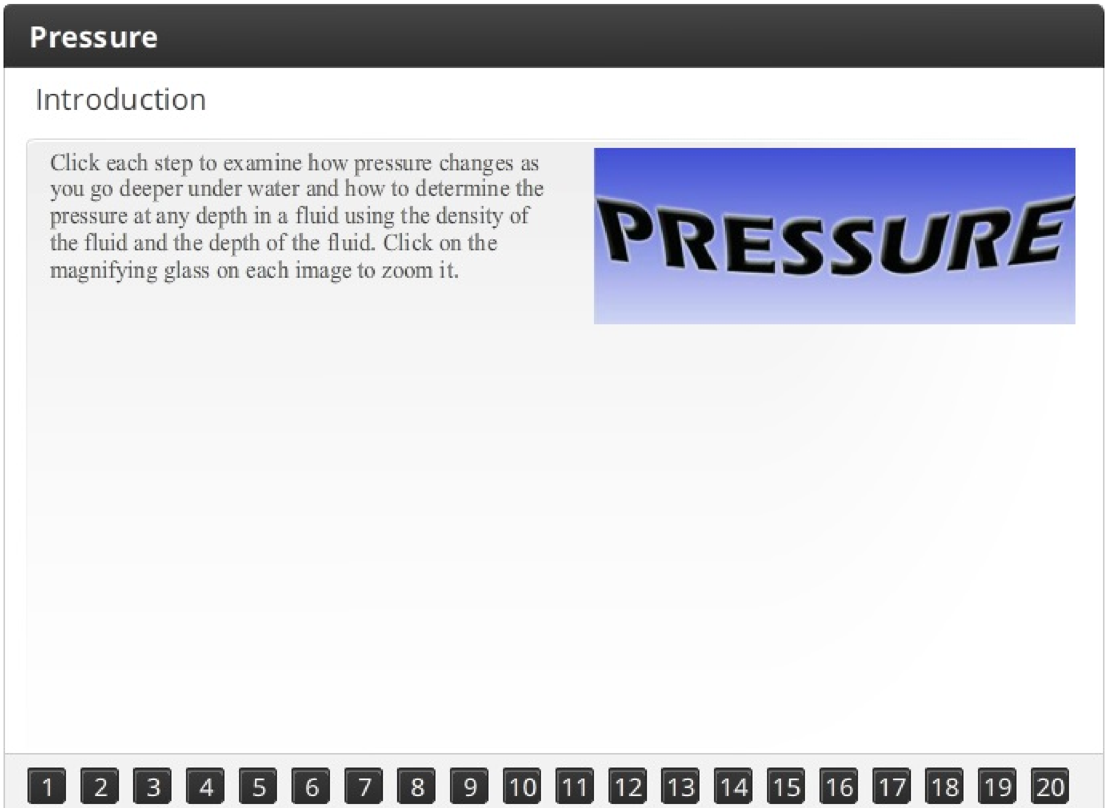
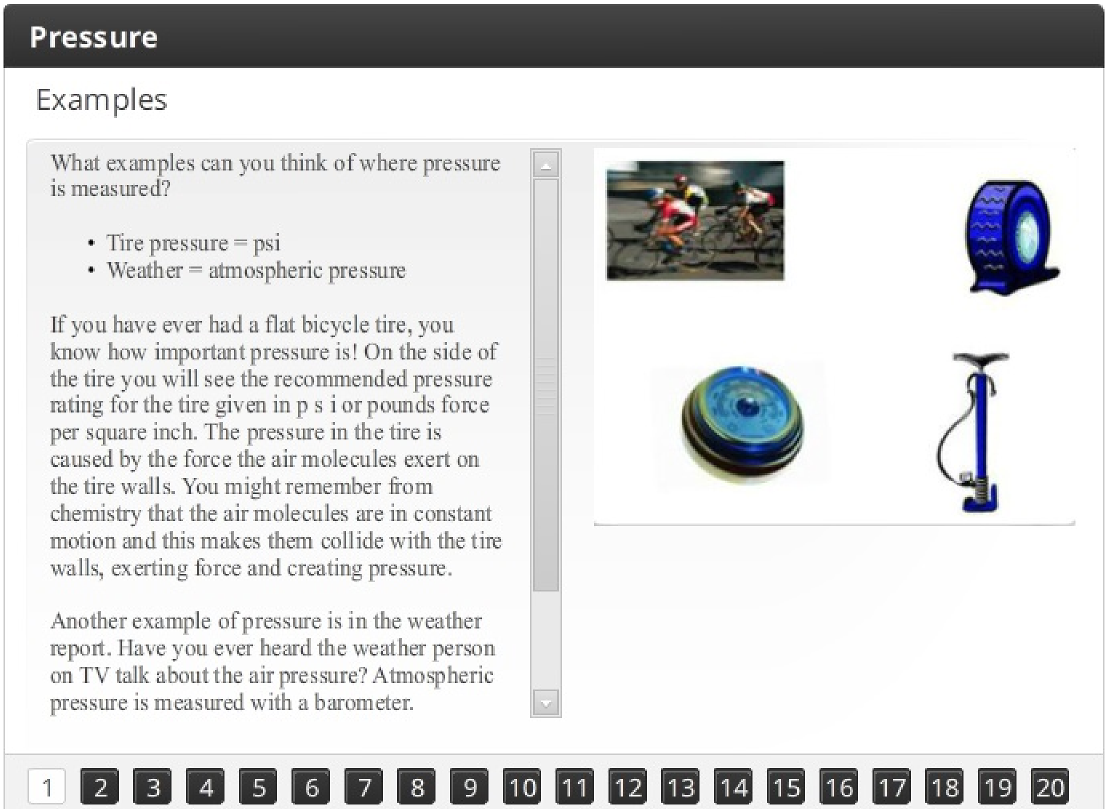
Module 9: Fluids
Topic 1 Content: Pressure

Introduction



Click each step to examine how pressure changes as you go deeper under water and how to determine the pressure at any depth in a fluid using the density of the fluid and the depth of the fluid. Click on the magnifying glass on each image to zoom it.

Examples



What examples can you think of where pressure is measured?

- Tire pressure = psi
- Weather = atmospheric pressure

If you have ever had a flat bicycle tire, you know how important pressure is! On the side of the tire you will see the recommended pressure rating for the tire given in p s i or pounds force per square inch. The pressure in the tire is caused by the force the air molecules exert on the tire walls. You might remember from chemistry that the air molecules are in constant motion and this makes them collide with the tire walls, exerting force and creating pressure.

Another example of pressure is in the weather report. Have you ever heard the weather person on TV talk about the air pressure? Atmospheric pressure is measured with a barometer. Atmospheric pressure is caused by the weight of all of the air in the atmosphere pushing down on us. There are several different units used for pressure in different situations, you will learn about these later.

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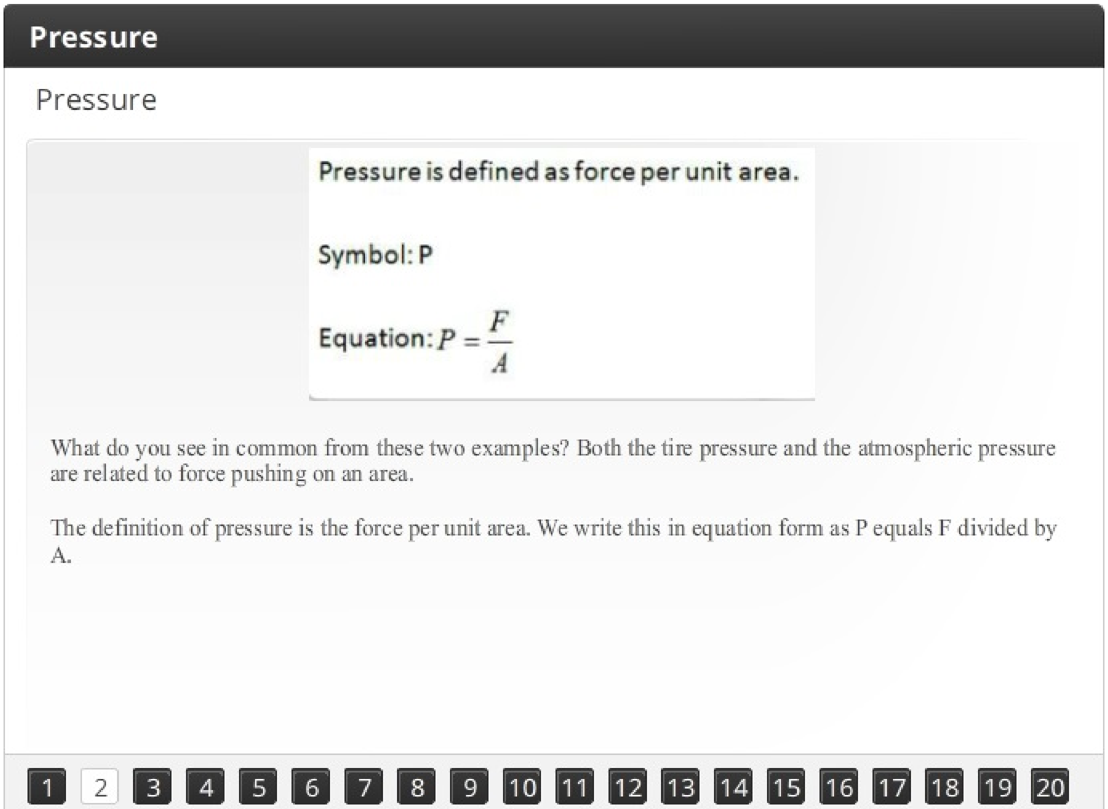
Pressure



What do you see in common from these two examples? Both the tire pressure and the atmospheric pressure are related to force pushing on an area.

The definition of pressure is the force per unit area. We write this in equation form as P equals F divided by A.

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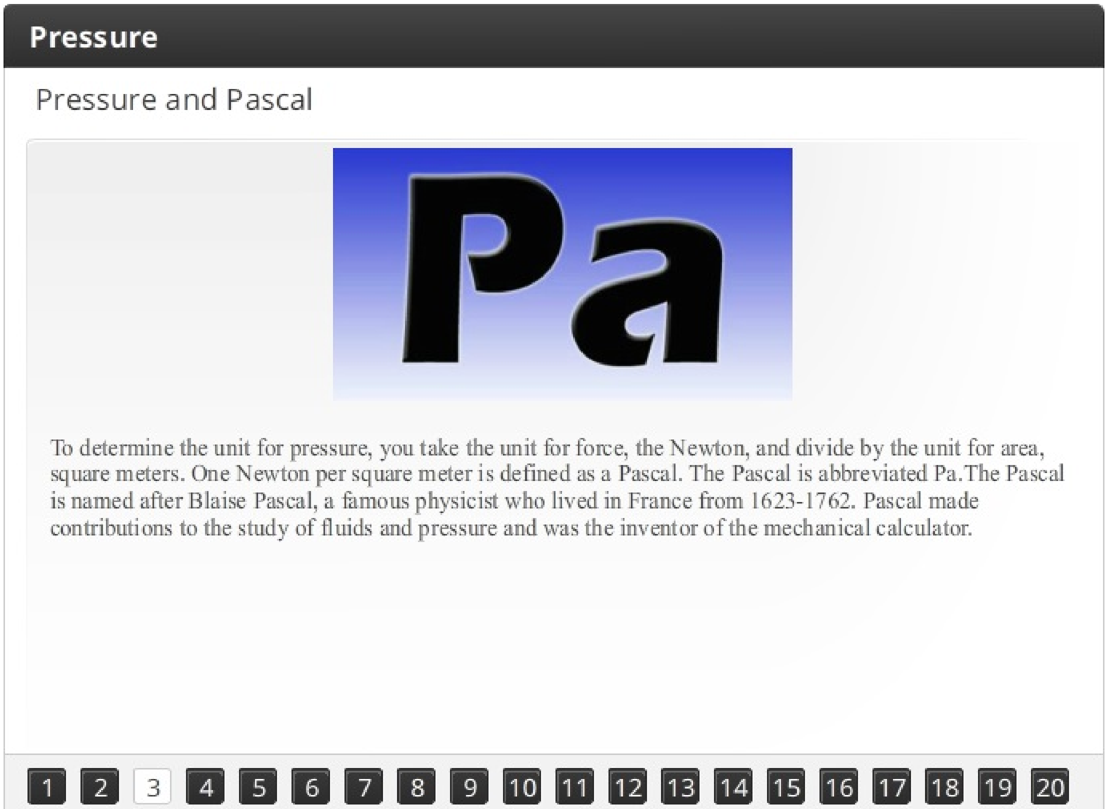
Pressure and Pascal



To determine the unit for pressure, you take the unit for force, the Newton, and divide by the unit for area, square meters. One Newton per square meter is defined as a Pascal. The Pascal is abbreviated Pa. The Pascal is named after Blaise Pascal, a famous physicist who lived in France from 1623-1762. Pascal made contributions to the study of fluids and pressure and was the inventor of the mechanical calculator.

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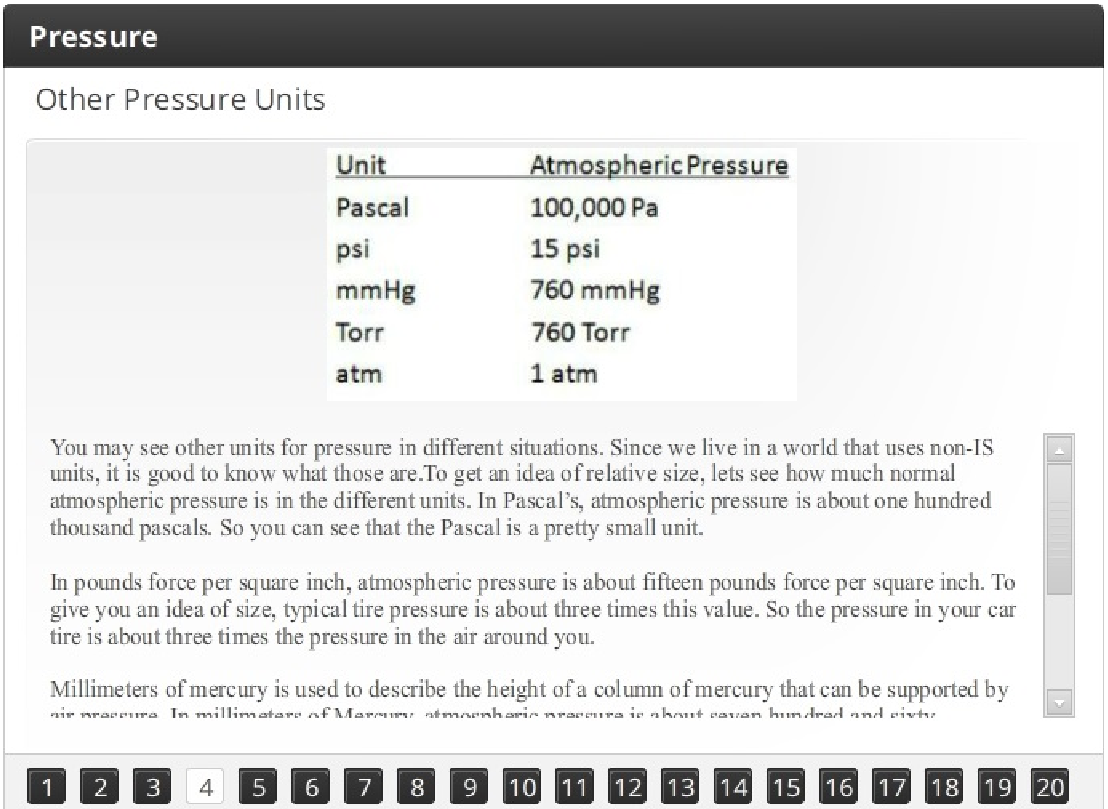
Other Pressure Units



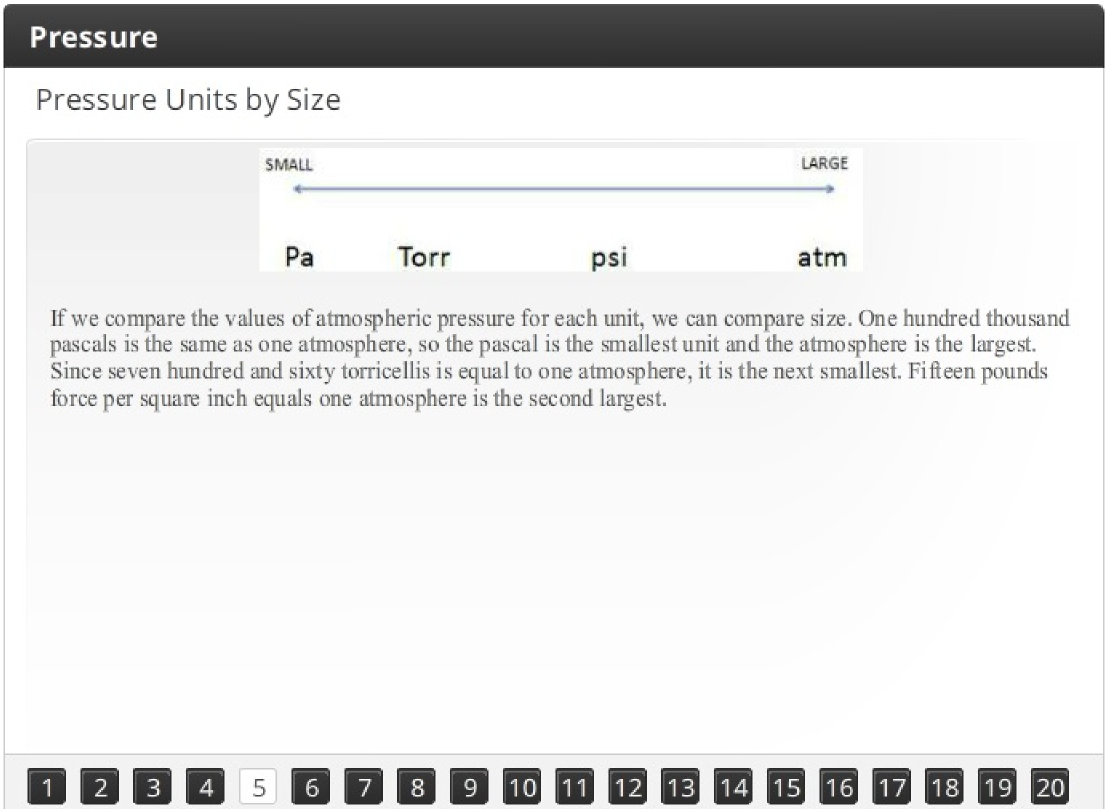
You may see other units for pressure in different situations. Since we live in a world that uses non-IS units, it is good to know what those are.To get an idea of relative size, lets see how much normal atmospheric pressure is in the different units. In Pascal's, atmospheric pressure is about one hundred thousand pascals. So you can see that the Pascal is a pretty small unit.

In pounds force per square inch, atmospheric pressure is about fifteen pounds force per square inch. To give you an idea of size, typical tire pressure is about three times this value. So the pressure in your car tire is about three times the pressure in the air around you.

Millimeters of mercury is used to describe the height of a column of mercury that can be supported by air pressure. In millimeters of Mercury, atmospheric pressure is about seven hundred and sixty millimeters of mercury. This unit is used by meteorologists when they describe regions of high or low pressure.

Torr is short for Torricelli, 1 torricelli is the same as 1 millimeter of mercury. 1 atmosphere is the pressure of the atmosphere. So, you can see that pressure can have many different units. In this course we will stick with Pascals, but you should be aware of the others in case you come across them in other situations.

Pressure Units by Size



If we compare the values of atmospheric pressure for each unit, we can compare size. One hundred thousand pascals is the same as one atmosphere, so the pascal is the smallest unit and the atmosphere is the largest. Since seven hundred and sixty torricellis is equal to one atmosphere, it is the next smallest. Fifteen pounds force per square inch equals one atmosphere is the second largest.

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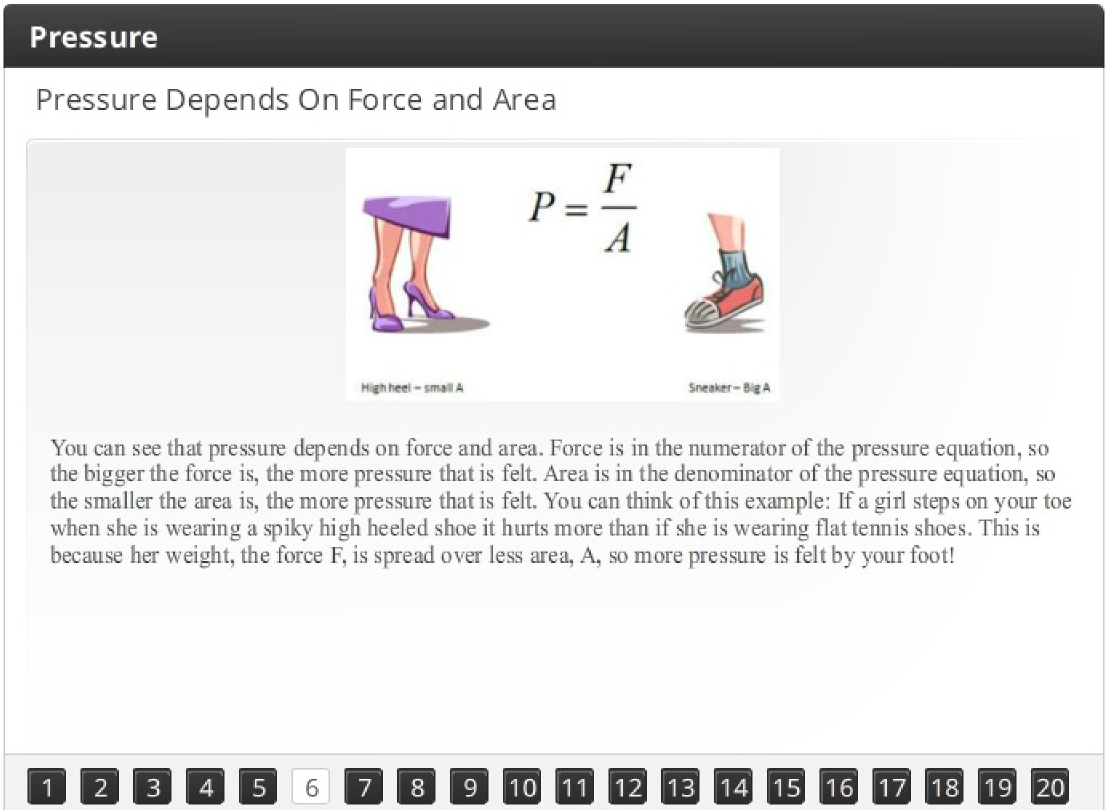
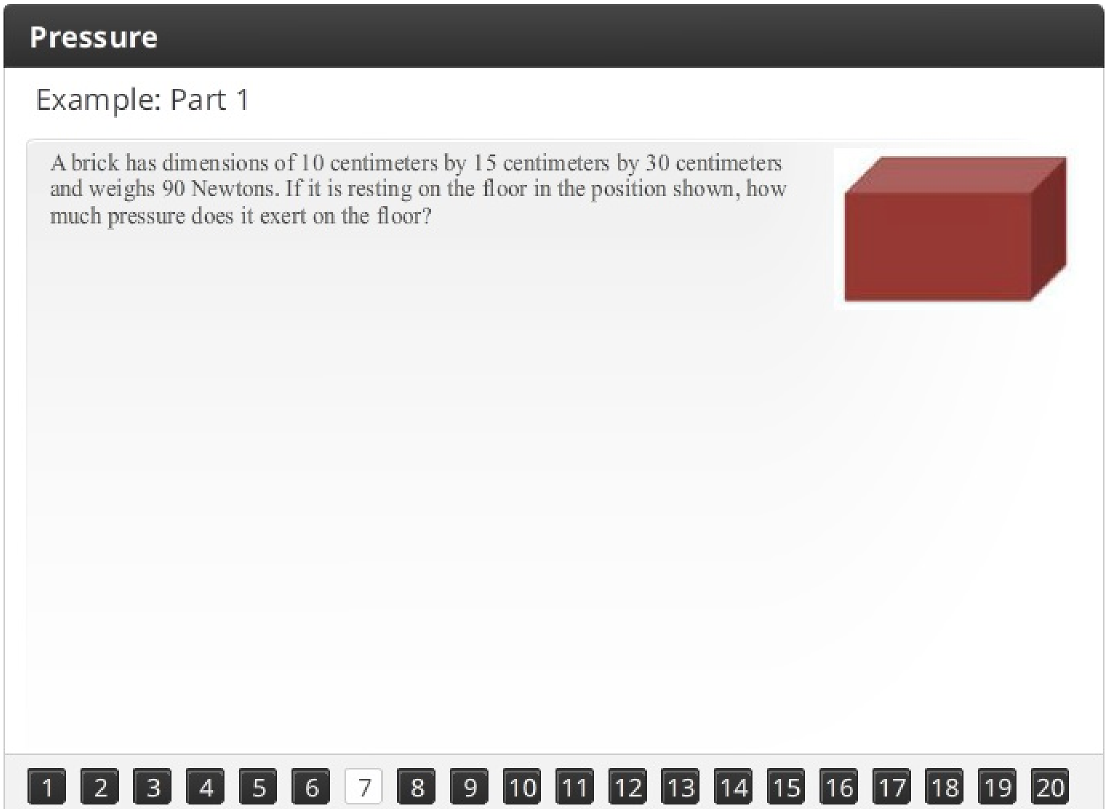
Pressure Depends On Force and Area



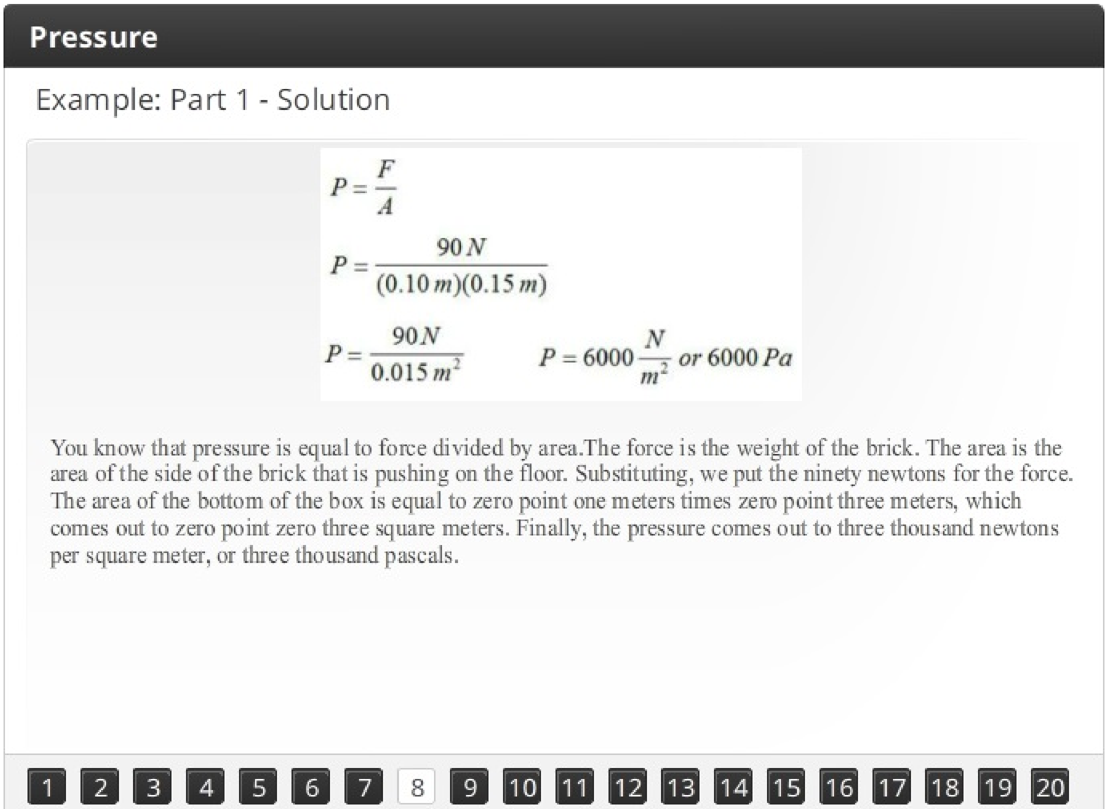
You can see that pressure depends on force and area. Force is in the numerator of the pressure equation, so the bigger the force is, the more pressure that is felt. Area is in the denominator of the pressure equation, so the smaller the area is, the more pressure that is felt. You can think of this example: If a girl steps on your toe when she is wearing a spiky high heeled shoe it hurts more than if she is wearing flat tennis shoes. This is because her weight, the force F, is spread over less area, A, so more pressure is felt by your foot!

Example: Part 1



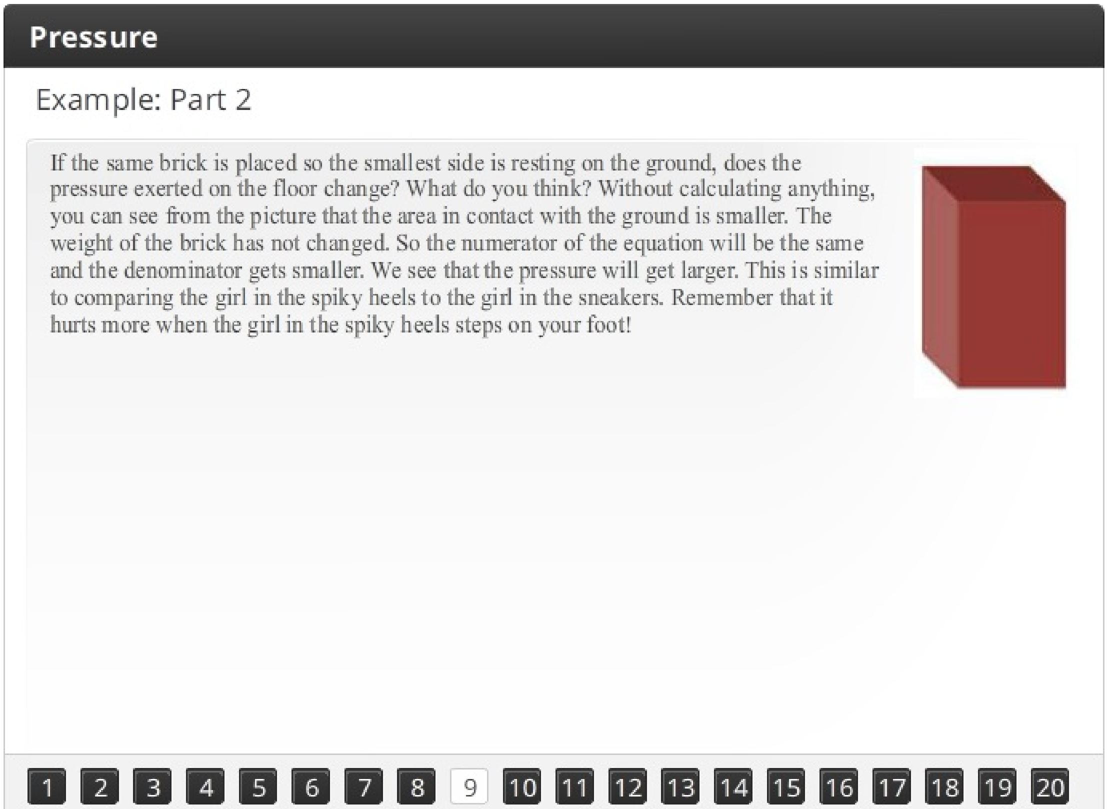
A brick has dimensions of 10 centimeters by 15 centimeters by 30 centimeters and weighs 90 Newtons. If it is resting on the floor in the position shown, how much pressure does it exert on the floor?

Example: Part 1 - Solution



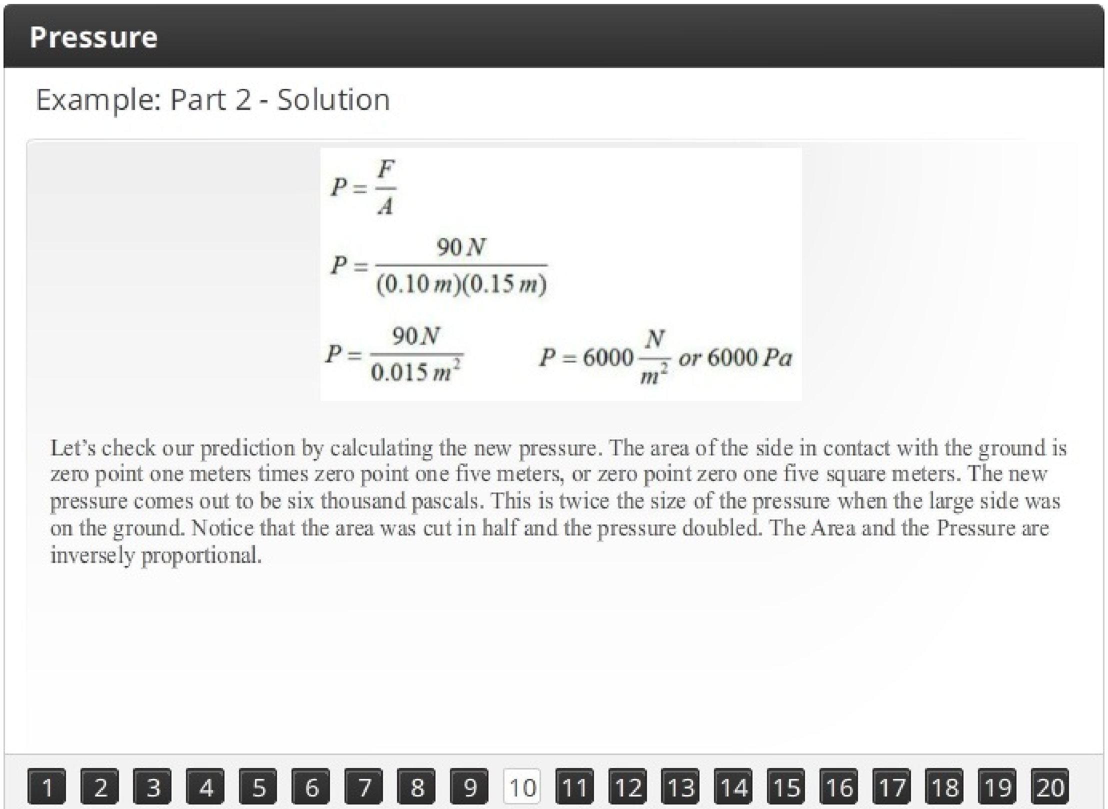
You know that pressure is equal to force divided by area. The force is the weight of the brick. The area is the area of the side of the brick that is pushing on the floor. Substituting, we put the ninety newtons for the force. The area of the bottom of the box is equal to zero point one meters times zero point three meters, which comes out to zero point zero three square meters. Finally, the pressure comes out to three thousand newtons per square meter, or three thousand pascals.

Example: Part 2



If the same brick is placed so the smallest side is resting on the ground, does the pressure exerted on the floor change? What do you think? Without calculating anything, you can see from the picture that the area in contact with the ground is smaller. The weight of the brick has not changed. So the numerator of the equation will be the same and the denominator gets smaller. We see that the pressure will get larger. This is similar to comparing the girl in the spiky heels to the girl in the sneakers. Remember that it hurts more when the girl in the spiky heels steps on your foot!

Example: Part 2 - Solution



Let’s check our prediction by calculating the new pressure. The area of the side in contact with the ground is zero point one meters times zero point one five meters, or zero point zero one five square meters. The new pressure comes out to be six thousand pascals. This is twice the size of the pressure when the large side was on the ground. Notice that the area was cut in half and the pressure doubled. The Area and the Pressure are inversely proportional.

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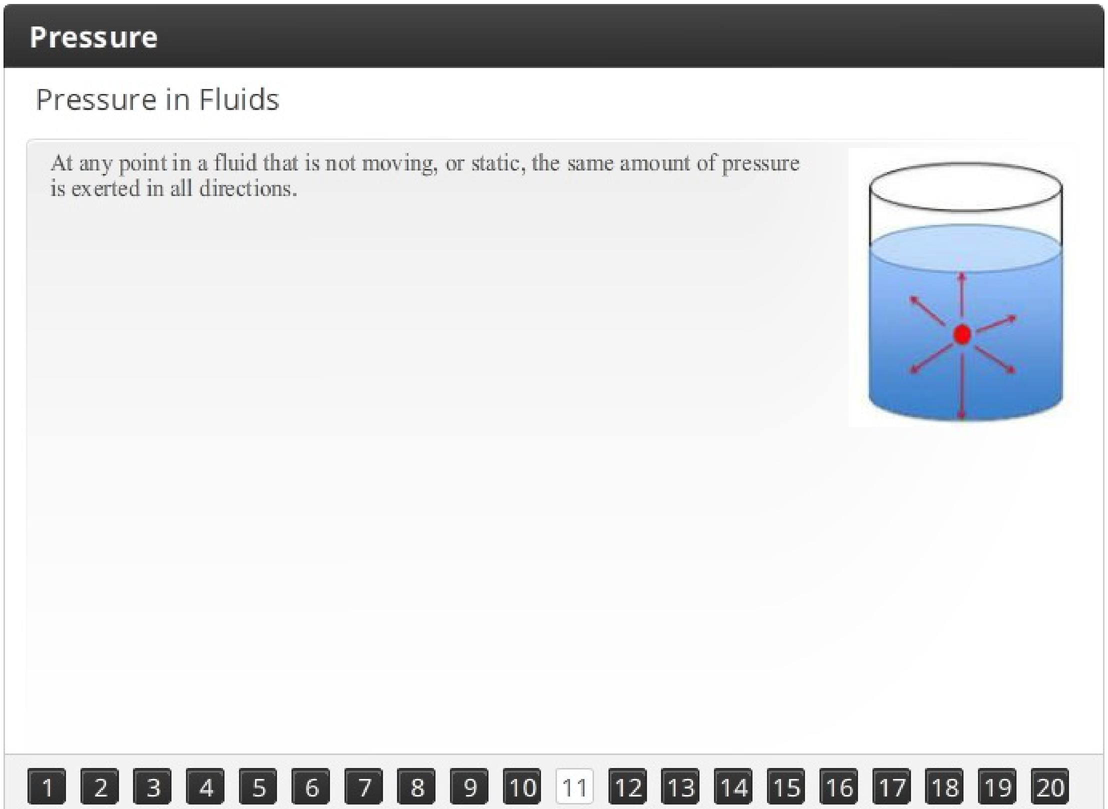
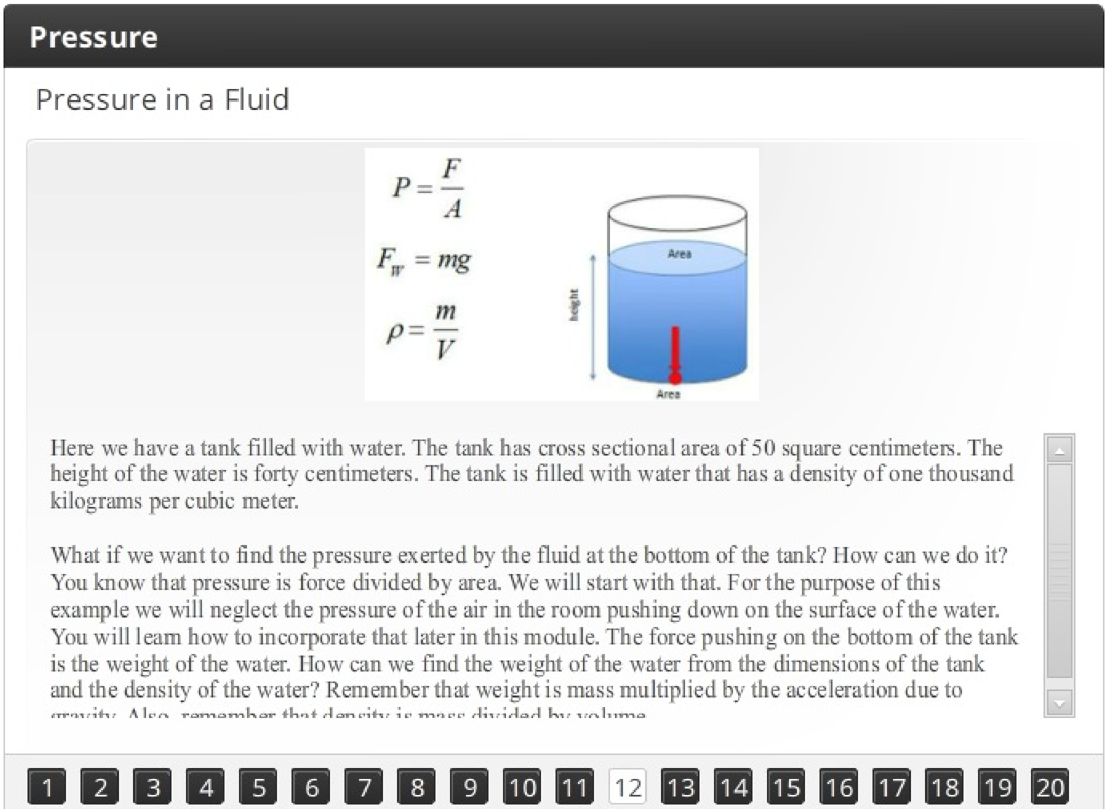
Pressure in Fluids



At any point in a fluid that is not moving, or static, the same amount of pressure is exerted in all directions.

Pressure in a Fluid



Here we have a tank filled with water. The tank has cross sectional area of 50 square centimeters. The height of the water is forty centimeters. The tank is filled with water that has a density of one thousand kilograms per cubic meter.

What if we want to find the pressure exerted by the fluid at the bottom of the tank? How can we do it? You know that pressure is force divided by area. We will start with that. For the purpose of this example we will neglect the pressure of the air in the room pushing down on the surface of the water. You will learn how to incorporate that later in this module. The force pushing on the bottom of the tank is the weight of the water. How can we find the weight of the water from the dimensions of the tank and the density of the water? Remember that weight is mass multiplied by the acceleration due to gravity. Also, remember that density is mass divided by volume.

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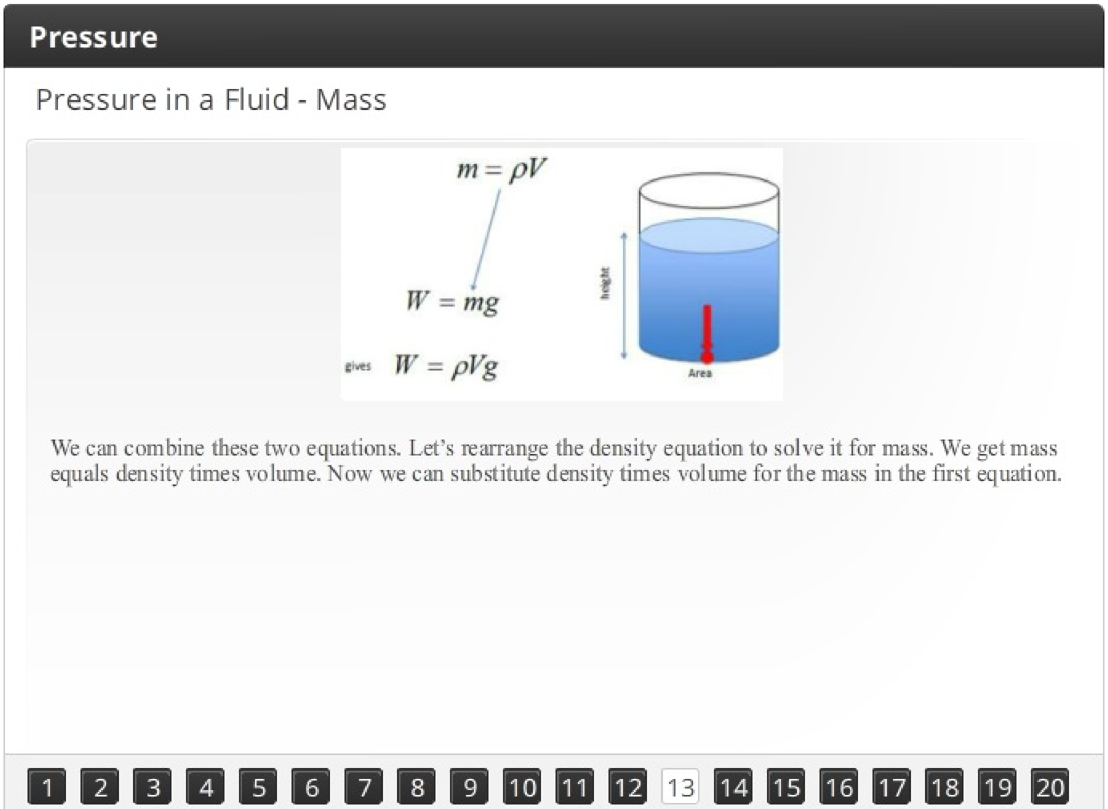
Pressure in a Fluid - Mass



We can combine these two equations. Let’s rearrange the density equation to solve it for mass. We get mass equals density times volume. Now we can substitute density times volume for the mass in the first equation.

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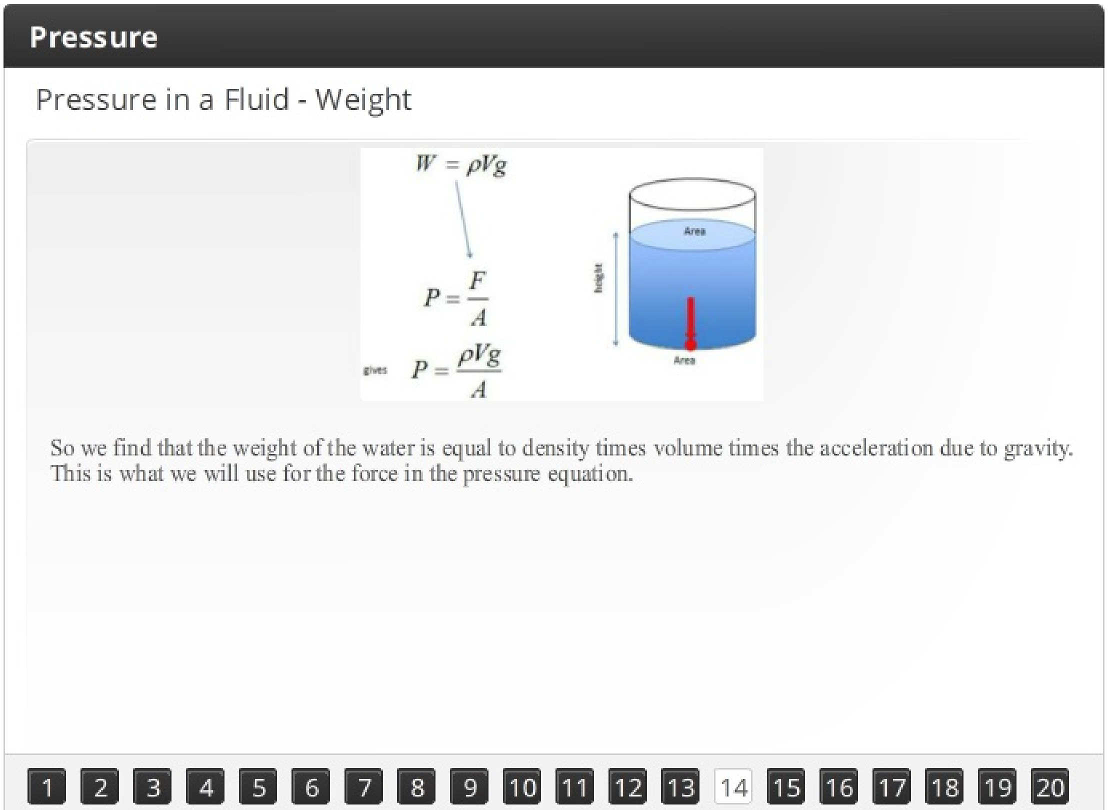
Pressure in a Fluid - Weight



So we find that the weight of the water is equal to density times volume times the acceleration due to gravity. This is what we will use for the force in the pressure equation.

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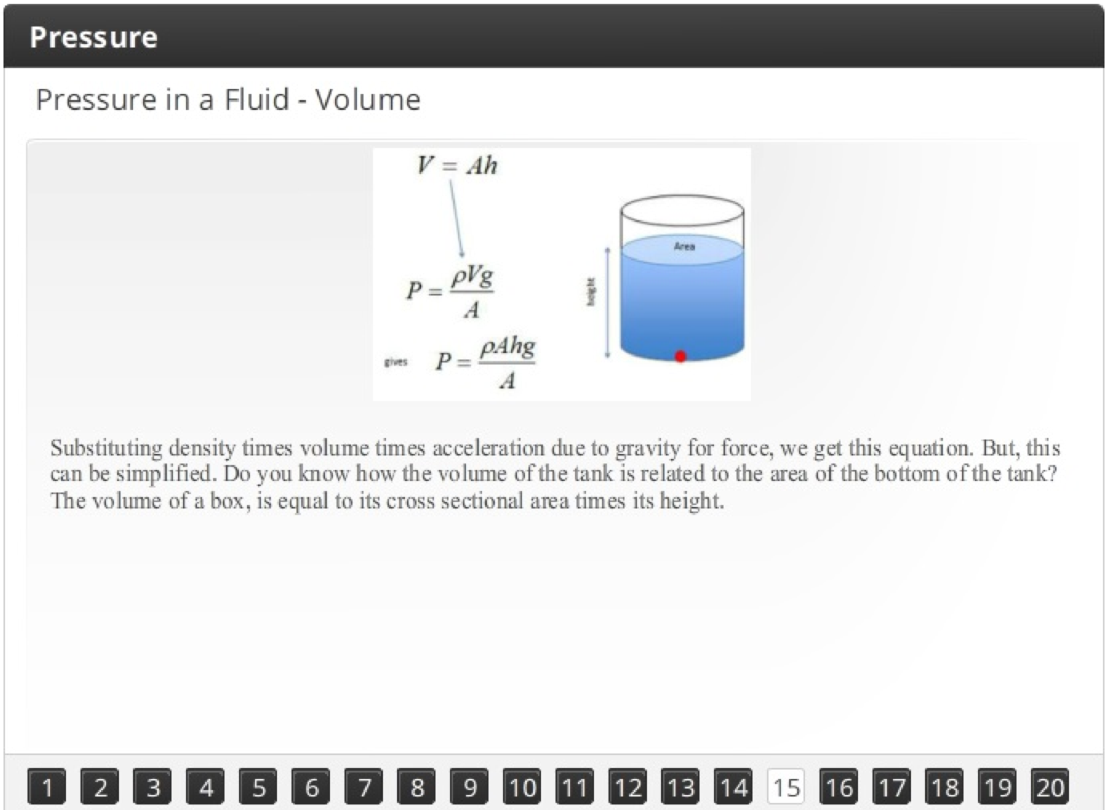
Pressure in a Fluid - Volume



Substituting density times volume times acceleration due to gravity for force, we get this equation. But, this can be simplified. Do you know how the volume of the tank is related to the area of the bottom of the tank? The volume of a box, is equal to its cross sectional area times its height.

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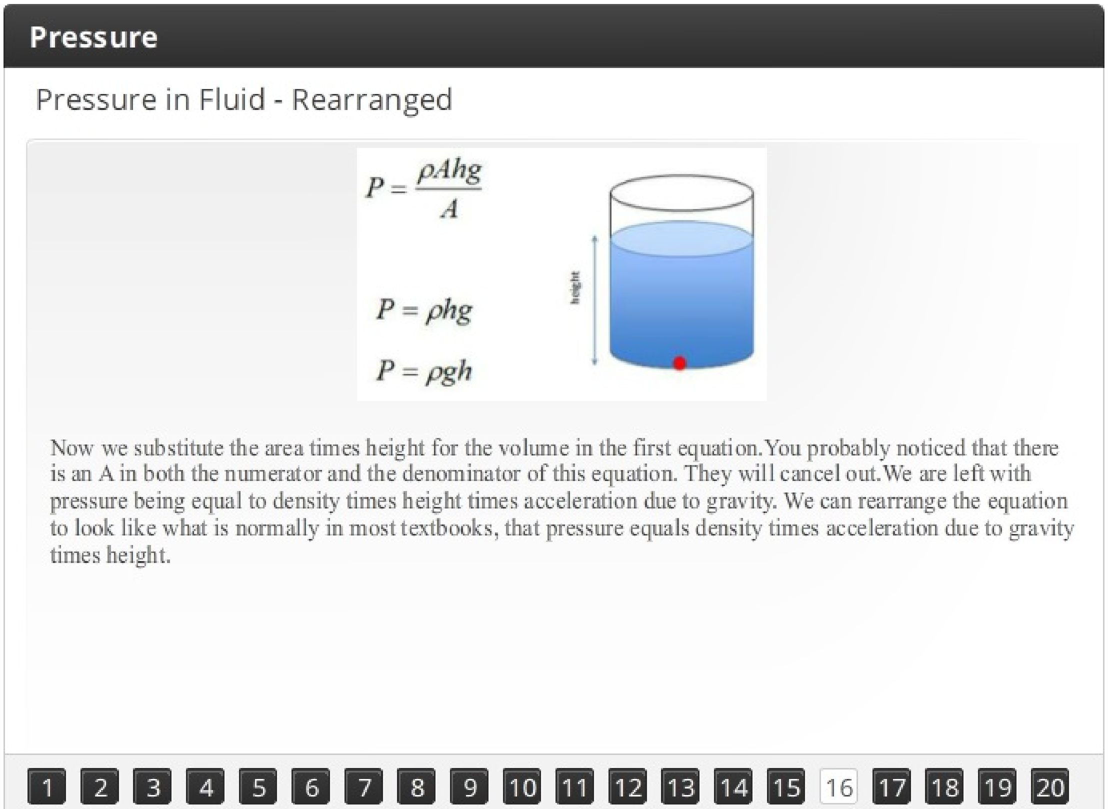
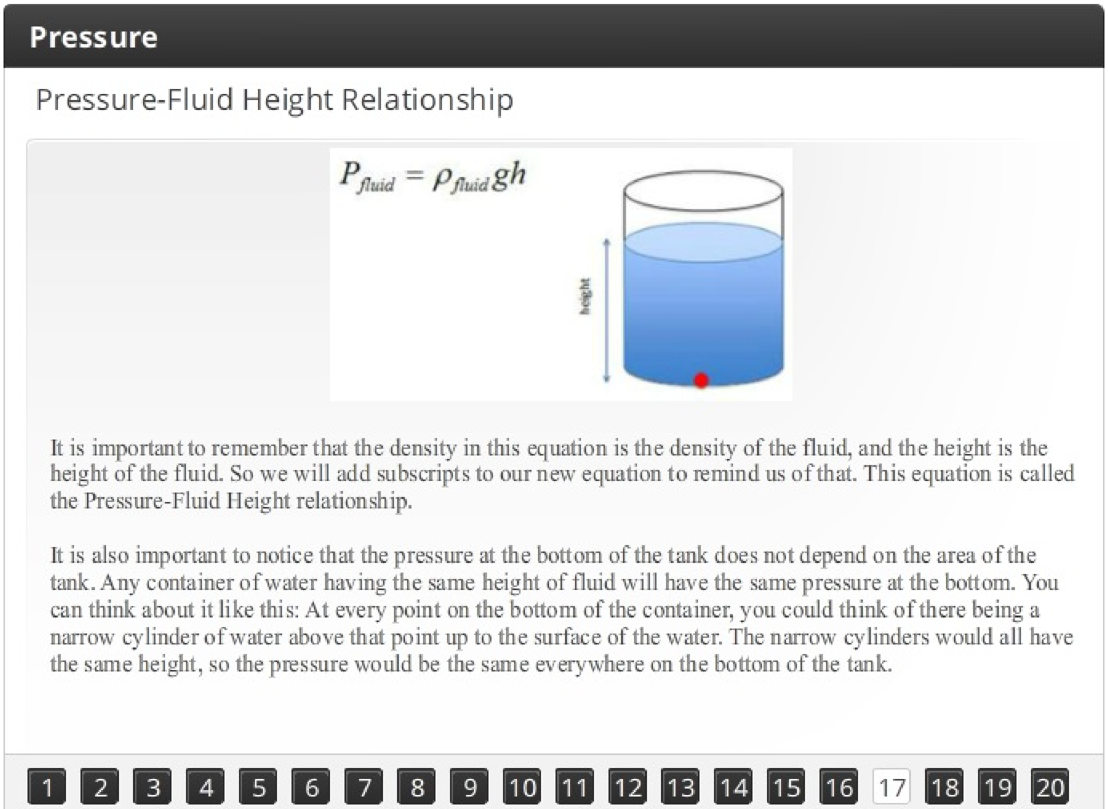
Pressure in Fluid - Rearranged



Now we substitute the area times height for the volume in the first equation. You probably noticed that there is an A in both the numerator and the denominator of this equation. They will cancel out. We are left with pressure being equal to density times height times acceleration due to gravity. We can rearrange the equation to look like what is normally in most textbooks, that pressure equals density times acceleration due to gravity times height.

Pressure-Fluid Height Relationship



It is important to remember that the density in this equation is the density of the fluid, and the height is the height of the fluid. So we will add subscripts to our new equation to remind us of that. This equation is called the Pressure-Fluid Height relationship.

It is also important to notice that the pressure at the bottom of the tank does not depend on the area of the tank. Any container of water having the same height of fluid will have the same pressure at the bottom. You can think about it like this: At every point on the bottom of the container, you could think of there being a narrow cylinder of water above that point up to the surface of the water. The narrow cylinders would all have the same height, so the pressure would be the same everywhere on the bottom of the tank.

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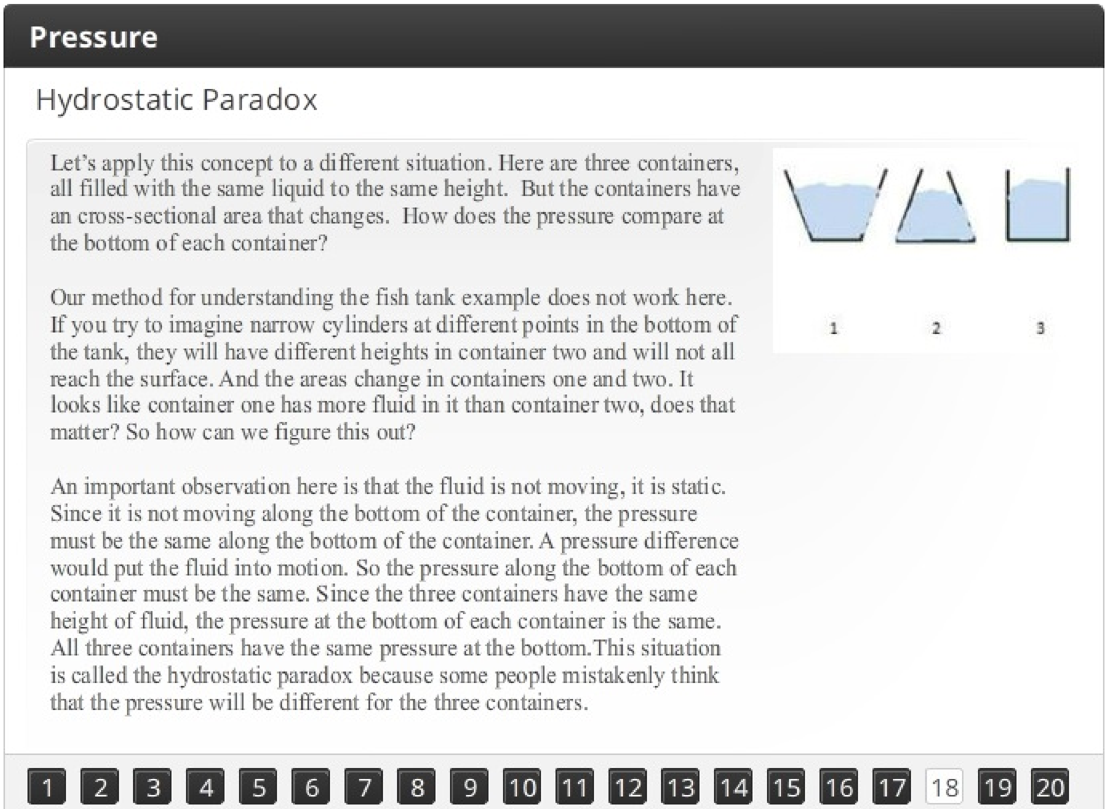
Hydrostatic Paradox

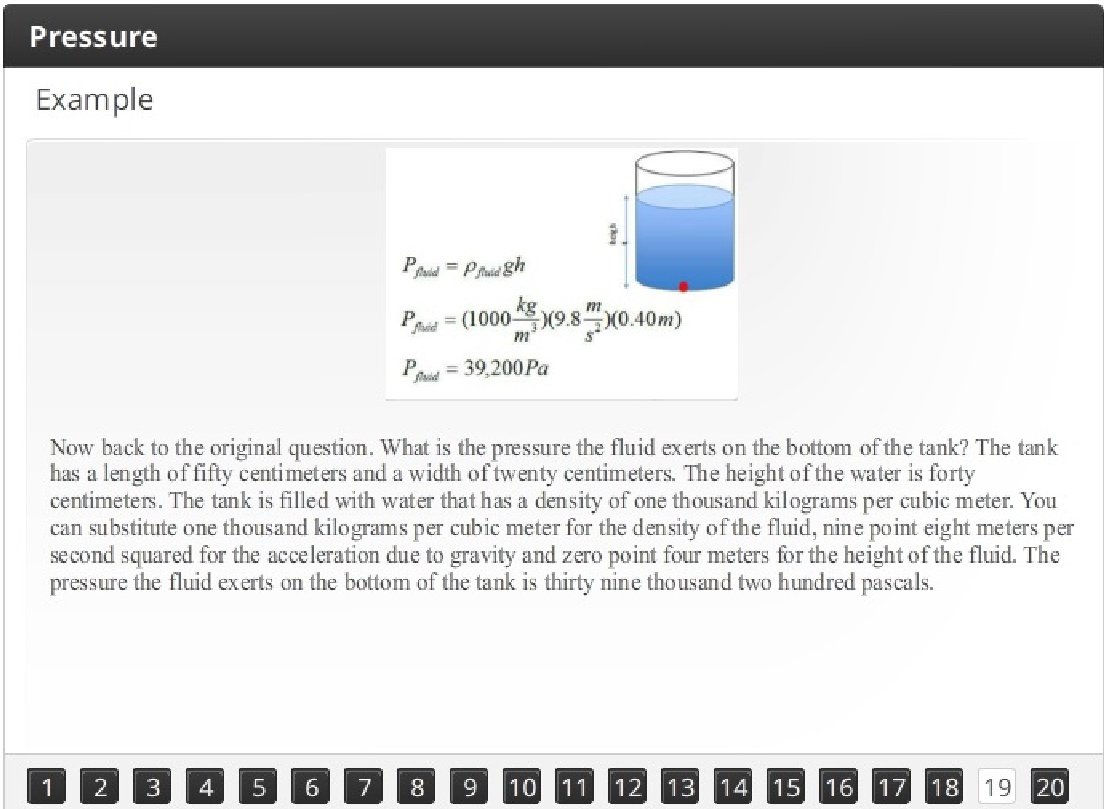


Let's apply this concept to a different situation. Here are three containers, all filled with the same liquid to the same height. But the containers have an cross-sectional area that changes. How does the pressure compare at the bottom of each container?

Our method for understanding the fish tank example does not work here. If you try to imagine narrow cylinders at different points in the bottom of the tank, they will have different heights in container two and will not all reach the surface. And the areas change in containers one and two. It looks like container one has more fluid in it than container two, does that matter? So how can we figure this out?

An important observation here is that the fluid is not moving, it is static. Since it is not moving along the bottom of the container, the pressure must be the same along the bottom of the container. A pressure difference would put the fluid into motion. So the pressure along the bottom of each container must be the same. Since the three containers have the same height of fluid, the pressure at the bottom of each container is the same. All three containers have the same pressure at the bottom. This situation is called the hydrostatic paradox because some people mistakenly think that the pressure will be different for the three containers.

Example



Now back to the original question. What is the pressure the fluid exerts on the bottom of the tank? The tank has a length of fifty centimeters and a width of twenty centimeters. The height of the water is forty centimeters. The tank is filled with water that has a density of one thousand kilograms per cubic meter. You can substitute one thousand kilograms per cubic meter for the density of the fluid, nine point eight meters per second squared for the acceleration due to gravity and zero point four meters for the height of the fluid. The pressure the fluid exerts on the bottom of the tank is thirty nine thousand two hundred pascals.

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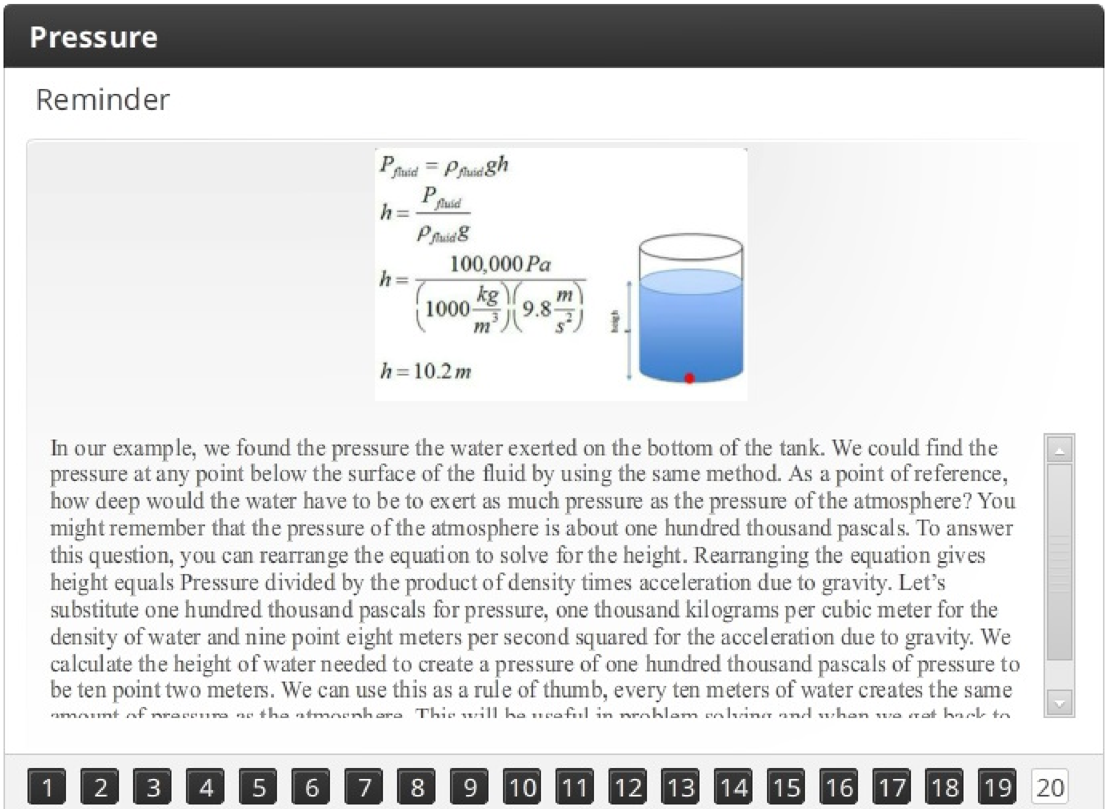
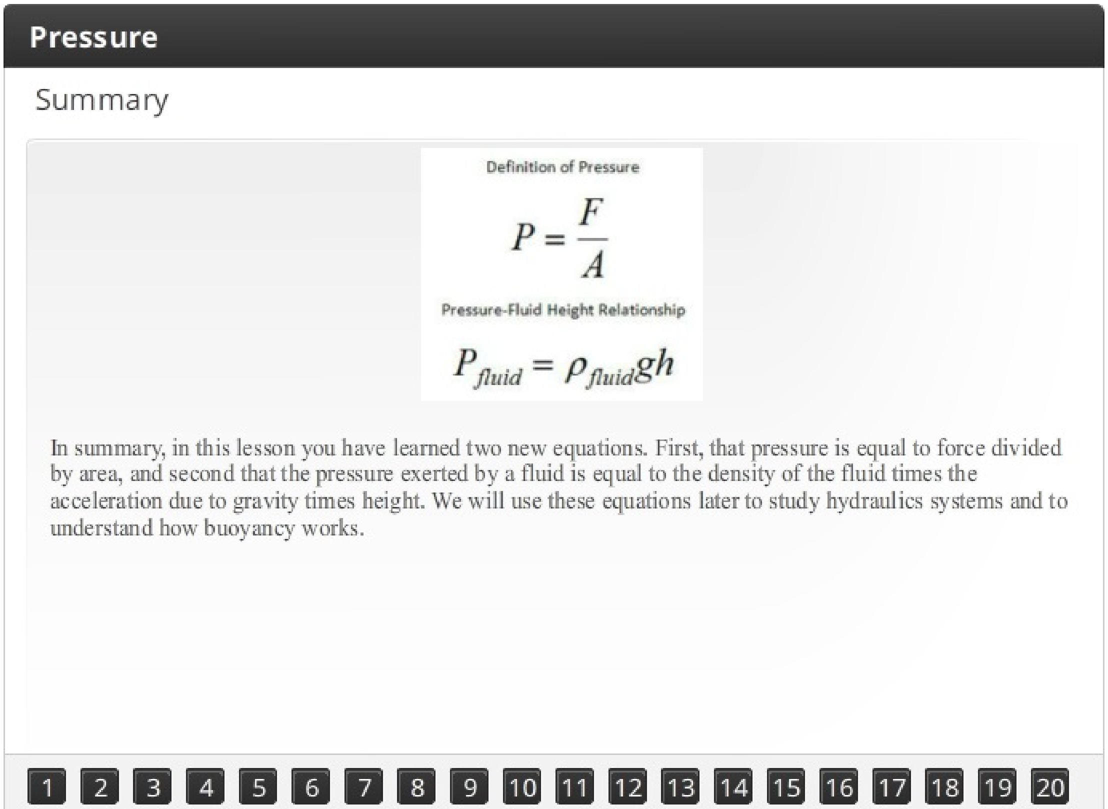
Reminder



In our example, we found the pressure the water exerted on the bottom of the tank. We could find the pressure at any point below the surface of the fluid by using the same method. As a point of reference, how deep would the water have to be to exert as much pressure as the pressure of the atmosphere? You might remember that the pressure of the atmosphere is about one hundred thousand pascals. To answer this question, you can rearrange the equation to solve for the height. Rearranging the equation gives height equals Pressure divided by the product of density times acceleration due to gravity. Let's substitute one hundred thousand pascals for pressure, one thousand kilograms per cubic meter for the density of water and nine point eight meters per second squared for the acceleration due to gravity. We calculate the height of water needed to create a pressure of one hundred thousand pascals of pressure to be ten point two meters. We can use this as a rule of thumb, every ten meters of water creates the same amount of pressure as the atmosphere. This will be useful in problem solving and when we get back to our discussion board question about scuba diving.

Summary



In summary, in this lesson you have learned two new equations. First, that pressure is equal to force divided by area, and second that the pressure exerted by a fluid is equal to the density of the fluid times the acceleration due to gravity times height. We will use these equations later to study hydraulics systems and to understand how buoyancy works.