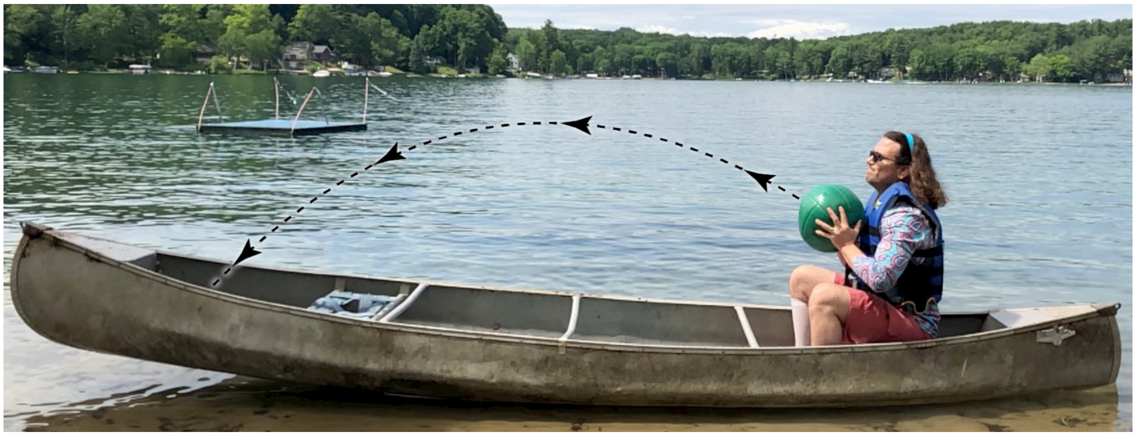
Flipping Physics Lecture Notes:

Throwing a Ball in a Boat - Demonstrating Center of Mass

When I throw the massive ball to the left such that it lands in the other end of the canoe, what will happen to the positions of the objects?



In the absence of an external force, a system of particles at rest will remain at rest. In other words, if the net external force on a system is zero, the center of mass of a system will remain in the same location. When the ball moves to the left, the center of mass of the system moves to the left *relative to the boat*. However, because the center of mass of the system does not change relative to planet Earth, *everything else in the system moves to the right.* In other words, if the ball goes to the left, the canoe and I must move to the right.

Before we do any calculations, let's ask one more question. When I throw the ball to the left such that it does not land in the canoe, what will happen?

In this case the ball is not actually a part of the system because the ball does not land in the boat. In other words, the net external force on the system does not equal zero; there is a net *rightward* external force on the system and the canoe and I will continue to move to the right at a constant velocity after releasing the ball.

Now back to the ball landing in the canoe. We can calculate how far the canoe and I move. In order to do so, we need to calculate the initial and final positions of the center of mass of the system and then take the difference between them.

Mass knowns: $m_b = 6.5kg; m_p = 72kg; m_c = 33kg$

Note: b = ball, c = canoe, p = mr.p

Position knowns: $x_{bi} = 108cm; x_{pi} = 133cm = x_{pf}; x_{ci} = 0 = x_{cf}; x_{bf} = -157cm$

Note: All positions are relative to the center of the canoe and the position final of the ball is negative because the final position of the ball is to the left of the zero reference point.

$$x_i = \frac{m_b x_{bi} + m_p x_{pi} + m_c x_{ci}}{m_b + m_p + m_c} = \frac{(6.5)(108) + (72)(133) + (33)(0)}{6.5 + 72 + 33} = 92.179\text{cm}$$

$$x_f = \frac{m_b x_{bf} + m_p x_{pf} + m_c x_{cf}}{m_b + m_p + m_c} = \frac{(6.5)(-157)+(72)(133)+(33)(0)}{6.5+72+35} = 76.731\text{cm}$$

$$\Delta \text{x}_{cm} = x_f - x_i = 76.731 - 92.179 = -15.448 \approx -15\text{cm}$$

In other words, the center of mass of the system moves 15 centimeters to the left *relative to the system*. In order for the center of mass of the system to stay in the same location relative to the rest of the planet, the zero reference point of the system (the center of the canoe) needs to move 15 centers to the right *relative to the planet*. The measurement is confirmed in the video and again, THE PHYSICS WORKS!!