Human Free-Body Diagram

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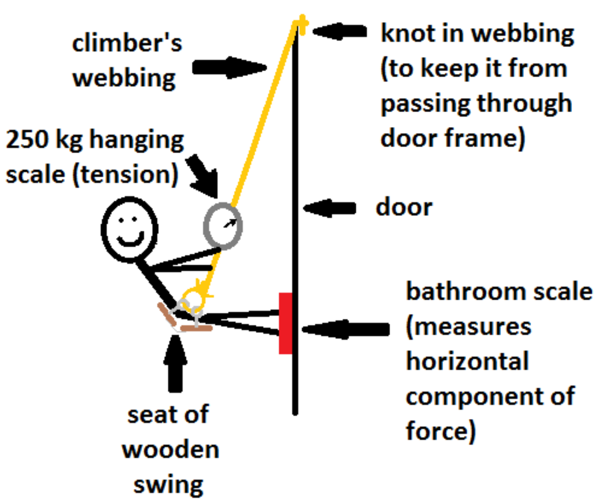
Motivation

Most physics students can learn to draw a correct free-body diagram for a climber attached to a rope at an angle:

With practice, students can successfully resolve the tension in the rope into its vertical and horizontal components, balanced by gravity and the normal force. However, many students never develop an intuitive feel for the process. This participatory demonstration places the student in the middle of the free-body diagram where he/she can directly observe and interact with the forces involved.

Set-Up

The set-up looks like the following:



Construction

The apparatus is constructed as follows:

Anchor Point: You need to anchor the rope onto something that can hold the weight of the student plus the apparatus. A door works well provided that it is solid, has sturdy hinges, is in good repair, and can be latched with the webbing jammed into the frame.

Important Note: the webbing will exert a substantial force on the door. The student should be on the side of the door ***without*** the hinges, to ensure that the force pulls the door ***into*** the door frame, not away from it.

Webbing: A roughly 6' length of 1" tubular nylon webbing is tied in a small loop. A large knot is tied in one end of the webbing, and the door is closed such that the knot is outside the door and the rest of the webbing is inside. (The knot keeps the webbing from being able to pass through the door slit.) A loop is tied in the other end of the webbing.

Hanging Scale: Carabiners are attached to the top and bottom of a 200-kg hanging scale (about $30 from Amazon). One carabiner is attached to the webbing (described above). The other end is attached to the seat (described below).

Seat: A wooden seat was made from two 24" lengths of 2" × 6" pressure-treated lumber, held together with a corner bracket that was widened to approximately a 120° angle. A ½" hole was drilled onto each side of both the seat bottom and seat back, and an eye bolt was bolted through each hole. A 10' piece of $^7\!/_{16}$" climbing rope was threaded through the two eye bolts on each side and knotted.

Bathroom Scale: During the demonstration, a bathroom scale is placed between the student's feet and the wall, to measure the normal force.

The apparatus should be set up so that the seat is 1–2 feet above the ground when hanging straight down from the door.

The Demonstration

A student climbs into the apparatus in a sitting position, with feet pressing into the door. (Tell the student to straighten his/her legs and push *hard*.) The student should be able to read the tension in the rope, as measured by the hanging scale.

The teacher places the bathroom scale on the wall for the student to "stand" on. The bathroom scale measures the horizontal component of the force.

The length of rope, height to the top of the door, and distance of the apparatus from the door can be measured using a tape measure or meter stick.

You will find that the tension in the rope is greater than the student's weight (as expected), and that the normal force is less than the student's weight (also as expected). However, exact calculations usually do not yield good results because the location of the student's center of mass varies, depending on the student's body position. (One student was delighted that we calculated her weight to be 115 pounds!)

Nevertheless, the demonstration is helpful for students to experience and see approximate values of the forces on a body (their own!) in static equilibrium.