The biophysics of walking

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Walking is something most of us take for granted. Modern day lifestyle having turned sedentary, it is now the prime form of exercise. Walking naturally brings to focus the limbs and by extension a memory of lessons of the skeletal and muscular system.

To understand walking one needs to know beyond the skeletal parts or muscles. There are principles of physics that can help us understand the stance and the movements we take when we walk. In fact if you want to be part of the footwear industry, to create different types of footwear you will need to have knowledge of principles one learns under both physics and biology.

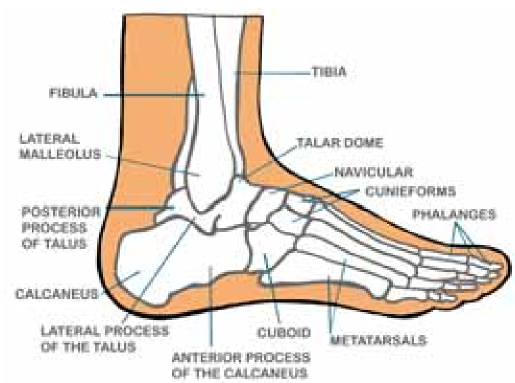
For the middle school classroom, walking is a very good activity to learn about the musculoskeletal system and the principles of force and pressure. It is not just walking, but any lesson that involves locomotion of animals or humans should be learnt in an integrated manner. Physics teachers can provide concrete experiences for abstract concepts relating to force, pressure, etc., if they use examples from the living world. Life and the chemical molecules that construct living organisms follow the same laws that physics tries to explain in the realm of non-living. Walking is one example.

To understand the mechanics of walking, it is important to understand the foot anatomy. The human foot is made of 26 bones, 33 joints and more than hundred muscles and tendons.

There are three parts to a foot – hind-foot, mid-foot and fore-foot.

The hind-foot: The ankle and the heel, which are important bones involved in movement, form the hind foot. The tibia or the longer bone of the leg forms a movable ankle joint with the tarsal bones of the foot. The heel bone is the largest tarsal bone and rests on the ground when the body is standing.

The mid-foot: The arches of the foot are formed by the tarsal bones and act as shock absorbers. The body weight is distributed among the seven tarsals, which can move slightly to provide minute adjustments to the position of the ankle and the foot.



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The forefoot: The metatarsals and phalanges of the five toes together form the forefoot. Like the tarsal bones, the position of the metatarsals can be adjusted to change the shape of the foot and affect balance and posture of the body. The phalanges can flex or extend to change the shape of the foot for balance and provide added leverage to the foot during walking.

The act of walking requires a change from the standing position when both the feet are on the ground, to lifting a foot. It seems easy enough to do, yet what is involved is a concept not learned in biology class but in physics.

The physics of walking

Force is a push or pull resulting from an interaction of one object with another. There are two types of forces – contact force and non-contact (or action at a distance) force.

While standing, the foot is in contact with the ground and the force acting upon it would be a contact force. When a person is standing the gravity exerts a downward force on the feet and the ground exerts an upward force on the feet. These two forces being equal and opposite the person does not move and stands.

> Gravity is something we all know and experience, but we can experience its effect by trying out this simple activity. Sit on a straight backed chair with your back erect and straight. Now without even the slightest movement towards front or back try to get up – get a friend to make sure that there is not the slightest movement to the front or back and you are trying to get up – straight and up. You will find that you are unable to get up unless you move slightly, very slightly, to the front or back to get up. This is because the force of gravity acting along the central axis of your body is keeping you down. Only by shifting it away – by moving forward or backward – are you able to overcome its effect.

When a person wants to walk, then a force greater than the force of gravity has to be exerted to lift the foot off the ground. A force can cause an object to undergo acceleration.

The force that the person exerts on the ground can be calculated using Newton's second law: **F = *m**a** where **F** is force (Newtons) ***m*** is mass (kg) and ***a*** is acceleration, (m/s^2) i.e., gravity in this case. A weighing scale will give a person's weight. Standard value for ***a*** on earth is 9.8 m/s^2.

This activity is fun and lets your students find out how much force they are exerting to lift their foot. Allow students to measure the force exerted by them when he/she is standing. Have a weighing scale in your class and let children work in pairs finding their weights and then calculating the force. The values that they will now use are real ones and not the hard to imagine ones usually provided to solve numerical (detested by many students).

For example: If the mass of a student is 40 kg then the force exerted by gravity is 392N.

$$40*9.8\ m/s^2 = 392N$$

$$m * a = F$$

Take the activity a step further. Students often confuse force and pressure. Use the opportunity to calculate pressure to understand that if the force that the students have calculated is applied on different areas then what they get is pressure. That is, if a force of 392N is applied over a small area it will create a higher pressure than if it were applied over a large area.

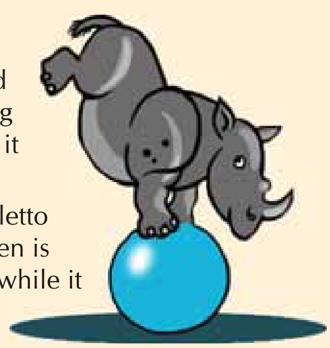
Let your students find this out through this simple activity;

All of them wear shoes/ sandals. In pairs, they have already calculated the force applied on the ground (which would include the weight of the footwear too). Now ask them to measure the area covered by their (feet) shoes while applying this force. To do that, they need to measure the length and breadth of the sole of their shoes and calculate the area.

Force, Pressure and the Rhinoceros

Imagine a rhino on a weighing scale. Would the rhino exert a – higher/lower/ same-force if it stood on two legs instead of four? Why?

What about pressure exerted by the rhino? Would a rhino standing on two legs exert a higher pressure than if it were standing on all its four legs? Why?



Do you know that the pressure under a stiletto heel caused by average sized Indian women is greater than that under an elephant's foot while it is walking? Can you explain?

Project Shoes

Did you know that

'paduka' or the wooden footwear used by Indians came in different shapes – like in the shape of a fish or crafted with embellishments, symbols etc. ?

High heeled shoes have a rich history worthy of study and were being used by Egyptians as far back as 3500BC?

For example: if it is 26 cm and 10 cm respectively then A = 26x10 = 260 cm^2. (Convert this to m^2 which is 0.26 m^2)

Give them the concept and the formula and ask them to do some calculations – Pressure is the force per unit area applied to an object. $P = F/A$

(P = Pressure (Pascals); Force = force perpendicular to the area (Newtons); A = Area (m^2)

$F = 392N$; $A = 0.26\ m^2$. So $P = F/A = 392N/0.26\ m^2 = 1507.7\ P$

Their calculation will give them the pressure their body is applying on the sole of the shoes, (taking for granted that the weight is evenly distributed).

Ask students to repeat measurements by calculating the area of only one shoe and find the pressure if they were standing only on one foot. Would the pressure exerted by the body be greater standing on one foot or both feet? The real values will help students understand that the same force applied over a small area will create a higher pressure; it will also help understand the difference between force and pressure.

So far it has been all about standing. To walk, the foot has to be lifted and in order to do that a force has to be exerted and the activity above gives an idea as to the quantum of force needed to lift the foot of the ground. How is this generated? It is now back to biology and the working of the muscles under the instructions of the nervous system, resulting in the lifting of the foot.

What happens when one walks? Ask students to walk and become aware of what they feel in their feet in particular and their body in general.

Recall that the forefoot consists of the toes and the ball of the foot, the mid-foot is the arch, and the rear foot is the heel. The major tendon in the foot is the plantar fasciitis. This stretches from the ball of the foot to the heel. When the foot first touches the ground during the walking movement, the plantar fasciitis acts as a shock absorber and tightens during the lifting phase of the stride, causing the foot to act as a lever. This is a simplified account of walking, but a heightened awareness of what happens to their (children's) feet during walking will help them improve their critical thinking skills and you can then introduce the concepts related to friction, the action of skeletal muscles and the coordinating systems of the human body.

Walking is not only a highly recommended activity for the sedentary lifestyle of humans, but it is also our primary form of locomotion. And whoever goes walking barefoot these days? Not only are shoes considered a must for walking, but footwear is and has always been a fashion statement. The human foot has not undergone any major change; but the footwear industry has, repeatedly. History will vouch for its incredible journey and modern day advertisements will serve you as witness. Footwear designing is a great career option but it requires a clear understanding of the principles learnt in your physics, biology, and to an extent chemistry, perhaps even geography classes.

In short, walking is an activity that can teach several concepts learnt in biology and physics in an integrated manner.

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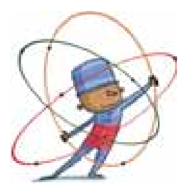
Who will exert more pressure – a woman wearing a walking shoe that has a flat heel or one wearing a shoe with a stiletto heel? Why?



Whales talk to each other by making a loud clicking noise. The sound waves travel extremely well underwater so they can hear each other from 100 miles away.