Writeup on Gecko Foot:

Have the Gecko in the room, preferably in a clear walled box, plastic or glass that can be turned upside down.

Ques: Ever had a Gecko for a pet?
Yes: Ask the student to describe their observation, especially with reference to Gecko climbing.

Ques: What do you know about the Gecko? What is the most interesting fact that you know about the Gecko?
Get all possible answers; give pointers that may lead to the climbing ability.

Ques: What could the mechanism with which the Gecko climbs a wall be? Putting in the question as leading out to discussion and hypothesizing may help in case some one does know the right answers, or in case someone does know the answer: 'how would we test it out? Or how do you know, lets us convince ourselves that it is indeed the right answer.
Pass the Gecko in the box around or have the students come and observe it in small groups of 2 or 3. A magnifying glass is very helpful in this case.

Geckos's have the extraordinary ability to walk almost on any surface including polished glass. Lets us try to find the mechanism with which a Gecko climbs.
--Have the students discuss in small groups their observations, and possible mechanisms of climbing.

Use a board map as the discussion starts, have them come up the key ideas and split them into groups to test each hypothesis using small experiments or discussions. (With a smaller group, it may be easier to do this with one group) Then they can all come together as group and discuss the pros/cons of their solutions, this can give other groups a chance to learn and comment.

The easiest ones to test are the glue and suction cups.

Possible outcomes of student's discussion:

1. Glue/secretion
2. Suction
3. Claws or interlocking surfaces
4. Some kind of intermolecular attraction/force including electrostatic attraction

Ques: When some one comes up with one of the above solutions, ask them how can they tell if that is right just by observation.
Testing of different theories:

1. With glue/secretion: Observe the gecko walking on the clear walls in its box for presence of any residue (most types of glue will leave residue), also test with a sticky tape on different types of surfaces and draw conclusions on how surface roughness and surface contamination affects stickiness.

Expected conclusion is that Gecko's appear to have self-cleaning feet and that there are no glands to secrete on their feet.

2. Suction: Test the factors that influence suction. Test not only for different types of surface and contamination but also the wetness of the surface, suction cup size and angle of removal on force. Effect of vacuum on suction. Students will be provided the following information "The death of the gecko did not release the foot, also, in a vacuum chamber the dead gecko was still hanging on to the wall".

   "To tighten or loosen its grip, the gecko curls and uncurls its toes, repeating the process more than 15 times per second".

Expected conclusion is that unless there is a differential in pressure, suction cannot work and that suction does not work very well on trees, branches and rocks.

Electrostatic attraction: This is the attraction between electrically charged objects, for example a plastic comb rubbed with cloth can pick up small pieces of paper. But when researchers charged the surrounding air with X-rays to form charged molecules (ions), which would cause any charge to leak away, the feet still stuck.

Geckos are able to walk on atomically smooth silicon surface; the only surface they are unable to walk is Teflon!

The following section has to be imparted in entirety to the students:

The gecko's ability to adhere to vertical surfaces--even walk upside down on ceilings---is due to the special hierarchical structure of its toes.

"There is no glue involved," Instead, the traction results from a physical property known as the van der Waals forces, a transient attraction that can occur from atom to atom at the scale of molecules.

When a gecko places its foot on the wall and curls its toes, the tiny spatulae get so close to the nooks and crannies on the wall's surface that their atoms interact with the atoms of the wall, bringing the van der Waals forces into play. Van-der-waals forces are relatively weak forces when compared to normal bonding forces.
But for such weak forces to work, there must be an enormous intimate contact area between foot and surface, so that enough individual weak forces can add up to a very strong force.

The toes have very fine hairs (setae) packed 5,000 per mm^2 (three million per square inch). In turn, the end of each seta has about 400–1,000 branches ending in a spatula-like structure about 0.2–0.5 μm long. A single seta of the tokay gecko (Gekko gecko) is roughly 110 micrometers long and 4.2 micrometers wide. Each of a seta's branches ends in a thin, triangular spatula connected at its apex. The end is about 0.2 micrometer long and 0.2 micrometer wide. These spatulae can provide the necessary contact area.

With its specialized feet, a gecko's traction is so strong that it can hold more than 100 times its weight.

Each foot pad in a Tokay Gecko has an area of about 100 mm^2 (0.16 sq. inch) and can produce 10 N of adhesive force (enough to support two pounds). But an individual seta has an attractive force 10 times stronger than expected. In fact, one seta is strong enough to support an ant's weight, while a million could support a small child—about 10 N/cm^2, where 10 N is about the weight of 1 kg. So the gecko has plenty of attractive force to spare. This means it can handle the rough, irregular surfaces of its natural habitat.

Actually, the attractive force is far greater when the seta is gently pressed into the surface and then pulled along. The force also changes with the angle at which the hair is attached to the surface, so that the seta can detach at about 30°. These elaborate properties are exploited by the gecko's behavior of uncurling its toes when attaching, and unpeeling while detaching.

This means that the gecko can not only stick properly with each step, but also avoid getting stuck, all without using much energy.

The setae slide against the surface on which there is perpendicular preload as long as the pulling is less than a critical angle (15^0) after which the detachment occurs. This can be tested with the sticky tape or a refrigerator magnet too.

Test for pulling along (parallel) to the surface and measure/estimate the critical angle at which the detachment occurs. This test can also be used as a proof against adhesives or suction as an argument.

The deformation of a substance is dictated by its stiffness or elasticity, which is reflected in a quantity called Young's modulus, measured in pascals (newtons per square meter). High values correspond to extremely rigid materials such as diamond (10^{12} pascals or 1 terapascal); fat cells have some of the lowest values (100 pascals). Bulk β-keratin is fairly hard, with a Young's modulus ranging from 1.3 to 2.5 gigapascals in bird claws and feathers (the values for β-keratin in lizards remain unknown).

By contrast, a pressure-sensitive adhesive, like that used in masking tape, is made from a soft, viscoelastic material that is tacky—it spontaneously deforms to increase the area of surface contact and has a Young's modulus of below 100 kilopascals at 1 hertz, according to the so-called Dahlquist criterion. (Carl A. Dahlquist was a pioneering adhesives scientist at 3M.) Such adhesives can be attached and detached repeatedly without leaving a residue because they work primarily through weak intermolecular forces. However, they are prone to creep, degradation, self-adhesion and fouling. Structures made of β-keratin—such as gecko setae—should be too stiff to work like a pressure-sensitive adhesive. How can setae function as an adhesive if they are made of something so rigid? The answer lies in the micro- and nanostructure of the seta, according to a mathematical model developed in Prof. Ron Fearing's laboratory. His model represents setae as tiny cantilever beams that act as springs with an effective Young's modulus much lower than the gigapascal-hard β-keratin they are made of. The most recent experiments observed an effective modulus of about 100 kilopascals in *isolated arrays from tokay geckos—remarkably close to the upper limit of the Dahlquist criterion. The unique hierarchy of structures on the gecko toe results in a low effective modulus, which causes gecko adhesive to have some of the same properties as properly tacky materials without the drawbacks. The combination of strength (at the level of the keratin protein) and ease of deformation (at the level of the spatulae and setae) may enable gecko adhesive to tolerate heavy, repeated use without creep or degradation. And because setae have a nonsticky default state (i.e. their default state is non-sticky) and require mechanical deformation in order to adhere, they don't stick to each other or become fouled. The adhesion of gecko setae is programmable, direction-dependent and possesses a built-in release mechanism.*

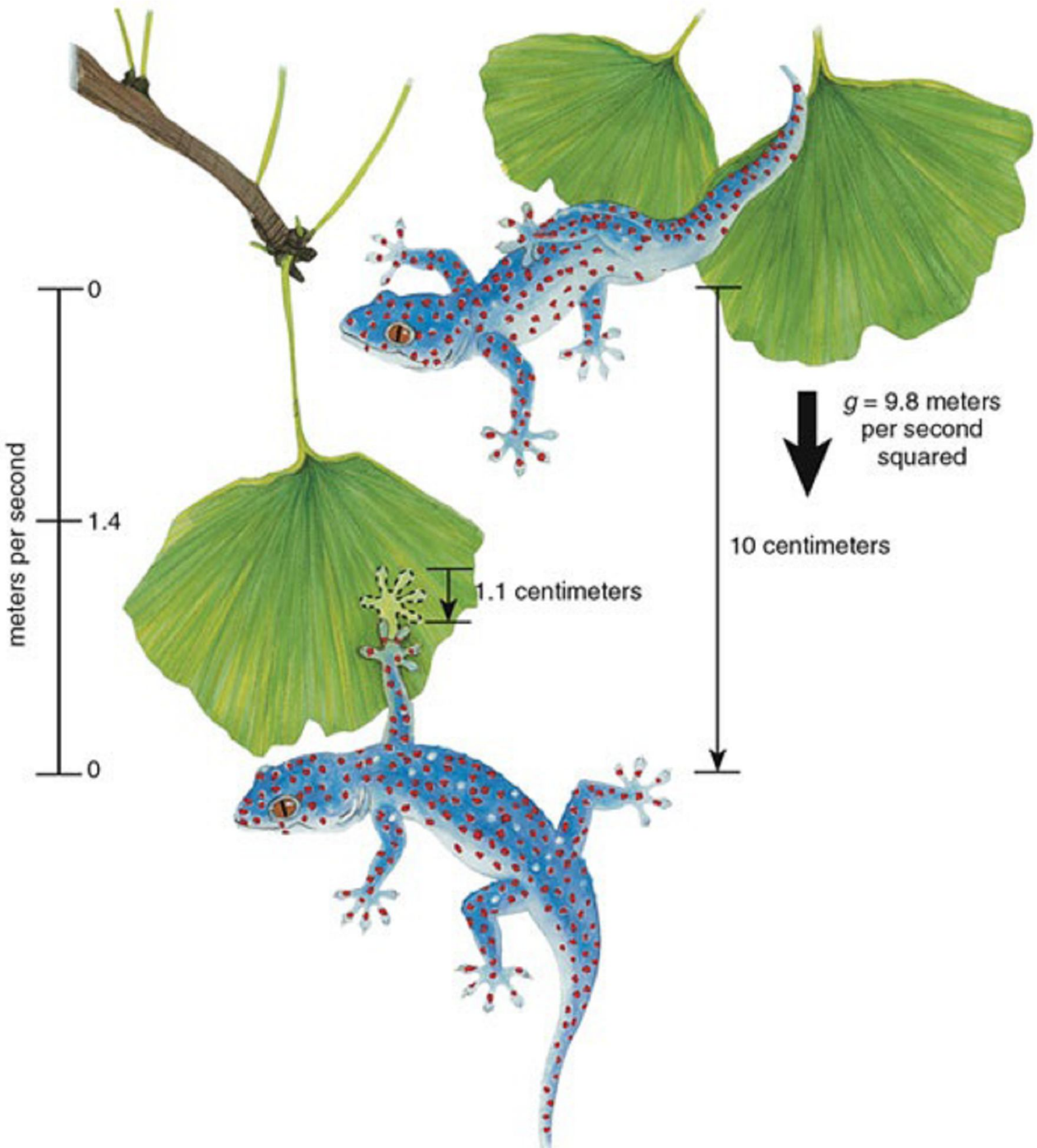
For advanced classes: Maybe a high school group or undergrads…

If students have knowledge of the equations of kinematics, then the following problem can be solved as a group in the class, if not, then a general discussion as presented above is sufficient.

"When geckos fall, they can arrest themselves by re-attaching their toes to passing leaves or branches, a recovery that requires much of a gecko's adhesive safety margin."

Consider the example of a 50-gram gecko falling from rest. If the gecko falls 10 centimeters before attaching a foot to a vertical surface, then it will be moving at 1.4 meters per second (neglecting air resistance). If the foot is able to produce 5 N of friction (though each foot is capable of producing close to 10 N), the gecko will come to a stop in 15 milliseconds after sliding 1.1 centimeters. In this theoretical example, recovering from a modest fall of 10 centimeters requires 50 percent of the shear capacity of one foot based on whole animal measurements (but still less than 4 percent of the theoretical maximum calculated from single setae).

Use the handout image of a gecko falling from rest. The solved problem and the image are attached.


0
1.4
0
meters per second
g = 9.8 meters per second squared
10 centimeters
1.1 centimeters

Solution to the problem

from the Equations of Kinematics

consider the example of a 50gm Gecko falling from Rest.

If the Gecko falls 10 cm [0.1 m] before attaching a foot to a vertical surface then ⟹

v_i = initial velocity
v_f = final velocity

$$d = v_i t + \frac{1}{2} a t^2$$ (a = acc due to gravity in m/s^2).

$$0.1\,m = 0 + \frac{1}{2}\, 9.8 \times t^2$$

$$\Rightarrow \quad t = 0.14\,sec.$$

Since $v_f = v_i + at$.

$$\Rightarrow \quad v_f = 1.37 \simeq 1.4\,m/s.$$

neglecting air resistance.

If the foot can produce 5N of friction.

then $F = ma = m\, v_f/t$

at $v_f = 1.4\,m/s$ & $m = 50\,gm$ the Gecko will stop in

$$\Rightarrow \quad t = 0.014\,sec \quad \text{or} \quad 14\,msec.$$

In 14 msec a gecko will come to a complete halt after slapping a toe on a passing leaf!

the distance it will slide on the leaf as it slows to complete halt can be calculated as

$$d = v_f t + \frac{1}{2} g t^2$$

$$\boxed{d = 1.1\,cm}$$ //

The force generated by a foot was calculated and at its max, a gecko foot can gen. twice the amount of force as compared to this problem!