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No Glue? No Problem! A Gecko's Guide to Bonding

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Lily Turaski is a lecturer in Materials Science and Engineering at Georgia Tech. She is passionate about combining fundamental materials science with engaging, real-world examples that are scalable even in large lectures. As the course coordinator for Georgia Tech's Introduction to Materials Science course, which serves a wide variety of STEM majors, she is passionate about teaching that encourages students from varied backgrounds to connect Materials Science and Engineering to their own career paths and everyday lives. She is particularly enthusiastic about creative classroom demonstrations—including the occasional gecko-assisted exploration of van der Waals interactions—that make materials science memorable for students of all backgrounds.

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Introduction:

When comparing bond strengths, van der Waals forces are at least an order of magnitude smaller than that of primary bonds, yet van der Waals interactions can still play a very important role in materials properties. By influencing material properties, van der Waals interactions play an important role in engineering applications, such as polymer mechanical behavior, composite interfaces, biomaterial surface engineering, and coatings or surface interactions. A specific example that is highly memorable is that of geckos, who use van der Waals interactions to climb up vertical walls and even walk upside-down on the ceiling.

These concepts are relevant across a range of materials science courses, starting early on in the introductory materials science class. This class is where students first learn structure-property relationships and begin to see how the very structure of atoms involved in a material impacts how it will behave. However, the relevance of these ideas extends well beyond the introductory level. Surface energy, intermolecular bonding, and interfacial interactions remain important in advanced courses, including thermodynamics, kinetics, polymers, and surface science. The activities described here are flexible and can be integrated into any course with a similar discussion addressing bond type, surface energy, or surface properties.

This paper describes a set of short, scalable classroom demonstrations designed for large lecture courses. Prior work has shown that interactive demonstrations can improve conceptual understanding and student engagement in STEM courses, particularly in large-enrollment settings [1] [2].

Learning Objectives:

The learning objectives for these activities can be varied based on the level of the class and the instructor's needs. Suggested learning objectives of these activities include:

1) **Identify** different primary and secondary bond types in materials systems
2) **Explain** how weak intermolecular interactions can collectively produce significant macroscopic effects
3) **Predict** how surface chemistry and structure influence adhesion and wettability
4) **Apply** bonding and surface energy concepts to broader MSE structure-property relationships

Classroom approach:

These demonstrations are implemented immediately following a lecture on bond types and general trends in bond energy. To frame the discussion, students consider that the same material can exhibit very different bonding interactions depending on context. For example, in polyethylene, covalent bonds dominate along a molecular chain, while van der Waals interactions govern interactions between neighboring chains. These secondary interactions are more than an order of magnitude weaker than primary bonds, as summarized in Table 1. This leads to the central question posed to students: If van der Waals bonds are so weak, when do they actually matter?

Table 1: Bond Energies of Selected Materials [3] [4]

Material	Bond energy (kJ/mol)	Bond type
Al	330	Metallic
Ag	285	Metallic
Si	450	Covalent
Si-O	799	Mixed covalent-ionic
C-C (diamond)	713	Covalent
C-C (SP3 polymer)	348	Covalent
C-H	411	Covalent
CH_4 (gaseous)	18	van der Waals *(intermolecular)*

Depending on the students' responses, we might get varied answers. One example is in polymers: van der Waals forces make a particular impact in polymer materials, where the between-chain interactions impact elastic modulus, yield strength, glass transition temperature, etc. In polymers, one reason van der Waals interactions become important is due to the large amount of overlap between chains – large numbers of weak interactions add up! Van der Waals interactions also influence broader engineering surface interactions, including interfaces in composites and behavior of coatings.

Another answer (and far more memorable for students): geckos! Geckos use van der Waals bonds to adhere to surfaces, and to scale vertical glass walls [5], [6], [7]. The activities that follow help us better understand van der Waals bonding and material surfaces.

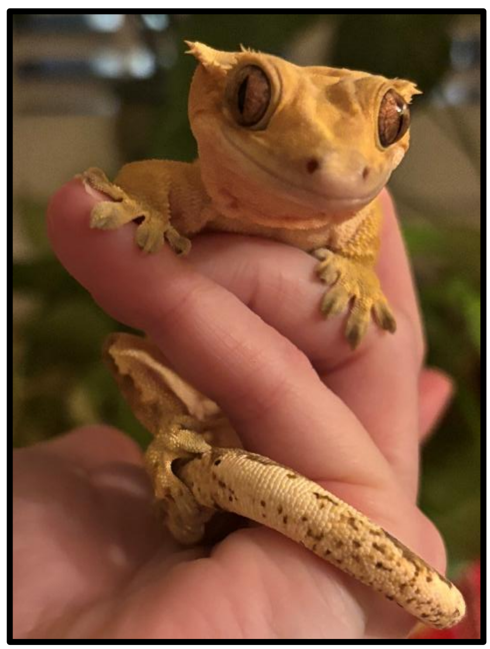

Figure 1: Diesel Truck, gecko

Introduction of Co-Author:

My co-author on this paper and my collaborator in the classroom is Mr. Diesel Truck, a crested gecko with over four years of dedicated experience in the application of van der Waals forces.

Geckos are nature's van der Waals experts, using the hierarchical nanostructure of their foot pads to have both strong and reversible bonding to almost any type of surface.

Activity 1: Examining the surface of gecko feet

The first activity guides students to answer the question: *How can a gecko support its own weight with only van der Waals interactions?*

A USB mini-microscope is used to image Diesel Truck's footpads in real time. The microscope is connected to the lecture projector, allowing all students—particularly in large classes—to observe the macro- and mesoscale structure of the feet (Fig. 2). While micro- and nanoscale features are not resolvable in a live demonstration, scanning electron microscopy (SEM) images from the literature are shown to complete the structural hierarchy (Fig. 3).

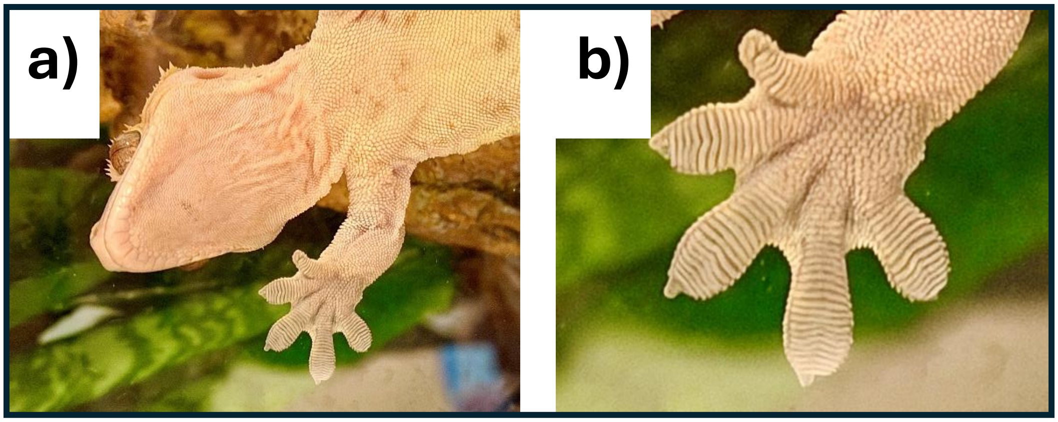

Figure 2: a) Macrostructure and b) mesostructure of Diesel Truck's footpads, illustrating the larger-scale hierarchical structures visible to students during the live demonstration

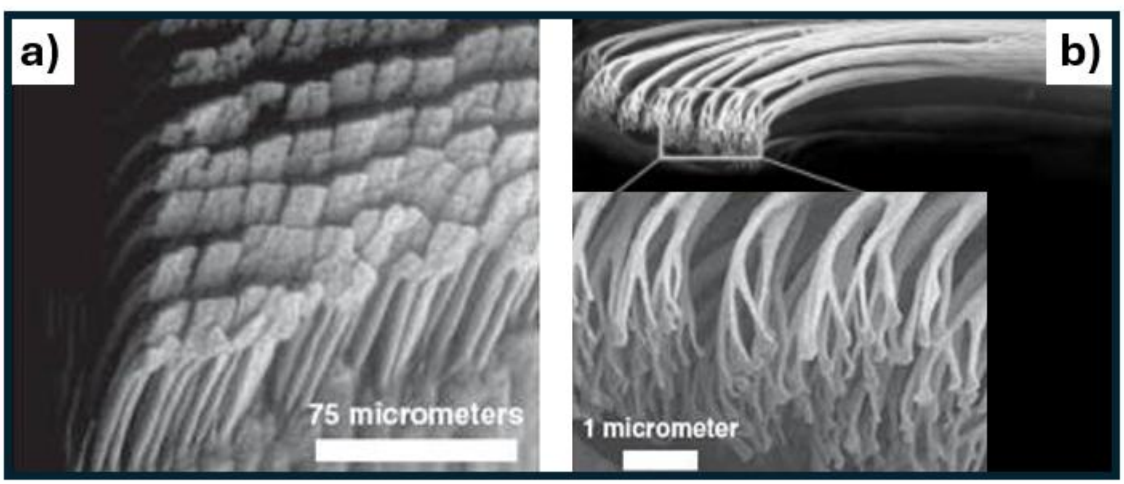

Figure 3: a) Microstructure (setae) and (b) nanostructure (spatulae) of Gecko feet visible via SEM, from literature [8]

Students observe that the footpads consist of a hierarchical structure terminating in billions of nanoscale setae. Although each individual van der Waals interaction is weak, the enormous number of contact points results in a large net adhesive force. This observation reinforces the idea that many weak interactions can collectively produce strong macroscopic effects, an idea that students have already encountered in the context of polymer chain length and entanglement. Students can also compare the performance of bio-inspired "gecko tape," which works due to similar nanostructuring [6], [7]. Gecko tape, also frequently labeled as nano tape, can be purchased at a variety of online retailers.

Activity 2: Gecko-surface interactions

The second activity guides students to answer the question, "*Are all surfaces the same?*"

Students compare how Diesel Truck interacts with different material surfaces, such as a plastic sheet, wooden board, cotton shirt, or pane of glass. As I progress through the various surfaces, I ask students to predict which materials he will be able to climb on. This turns the discussion into a low-stakes think-predict-observe exercise. (Answer: Diesel Truck is easily able to climb each of the items mentioned above!) I then ask students to predict a surface that he *cannot* climb on (with optional hints such as "non-stick"). I then reveal the final material surface to test – a Teflon pan – and ask students to predict: "Can Diesel Truck climb the Teflon pan?" (Answer: No – despite his expertise, Diesel Truck meets his match in Teflon. He is unable to maintain a grip and instead slides down.)

This leads to a guided discussion of what controls adhesion. Is it just surface roughness? Is it just surface hardness? In other words, is Diesel Truck's ability to climb based on being able to dig his claws into a surface? These hypotheses are tested directly. Cloth and wood provide greater surface roughness and more opportunities for the animal to hang on with claws, but glass is a very smooth surface (no pre-existing claw-holds) and has very high hardness (cannot scratch new claw-holds). And yet, Diesel Truck still easily climbs the glass. We then compare bond and/or surface energies of different materials, including the materials the Diesel Truck is asked to climb. Students then connect how surface energy influences the interactions between surfaces. Teflon's extremely low surface energy prevents Diesel Truck from climbing up the pan. For advanced courses, this discussion leads into teaching students how to calculate surface energy given bond strength, crystal structure, and Miller indices of the created surface. Surface energies of relevant materials are summarized in Table 2.

Table 2: Surface Energies of Selected Materials [3], [9], [10], [11]

Material	Surface Energy (mJ/m^2)
Al	870
Ag	1140
Si	1240
SiO2	3000
Wood	~40-60
Pure cotton cloth	~40-60
PET	44.6
PMMA	41.1
PTFE	18

Activity 3: Comparing how water interacts with different surfaces

The third activity guides students to measure surface properties. In a complementary project, students measure the contact angle of water droplets on different surfaces, creating a connection between molecular interactions, wetting behavior, and adhesion. This project has been implemented as a short out-of-class assignment to conserve lecture time and to allow for students to have more freedom and creativity when finding materials to test.

Students use a 0.2 mL dropper to place water droplets on flat surfaces and photograph the droplets from the side. ImageJ is then used to measure contact angles. Each student group must identify at least one hydrophilic surface (contact angle $< 90°$) and one hydrophobic surface (contact angle $> 90°$). Students then slowly tilt the surface and measure the angle at which the droplet begins to either slide or roll off.

Discussion prompts include:

- Why do you think each of these materials was hydrophobic or hydrophilic, considering the expected bonding?
- When can you use materials with each of these properties?

Students present their results via a short video report. A sample grading rubric is shown in Table 3.

Table 3: Sample Project Rubric

A description of the materials you tested	5
Video / image evidence of your contact angle measurements on each material, including reporting the average contact angle for each material (10 points)	10
Demonstrate that you were able to find both a hydrophobic and hydrophilic material (5 points)	5
Discuss why you think each material is hydrophilic or hydrophobic. Liquids usually wet solids with similar bonding, so consider that water has fairly polar bonds. (10 points)	10
Video / image evidence of the measured roll-off/sliding angle for each material, including reporting the average angle that you measured. (10 points)	10
Discuss whether your materials have roll-off or sliding behavior. (5 points)	5
End the video by discussing where you might use these properties of a material. (5 points)	5
Total points	50

Sounds fun, but I don't have a gecko. How can I bring this into my classroom?

While a live gecko is undeniably engaging, these activities are designed to be accessible even without one. Gecko tape is a relatively affordable material which can be used in tactile demonstrations. Additionally, for conference attendees, demonstration materials will be provided via a shared Dropbox link, allowing instructors to integrate prerecorded footage and discussion prompts within their classrooms.

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