

# Introductory College Physics Students' Explanations Of Friction And Related Phenomena At The Microscopic Level

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**Abstract.** We investigated introductory college physics students' explanations of friction and lubrication through semi-structured clinical interviews. Although students were able to construct explanations at the atomic scale, they tended to explain phenomena by using attributes of macroscopic objects. For instance, when they described atoms as balls, they tended to associate attributes of real balls to the attributes of the atoms. In the future our results will guide the design of teaching materials to enable students to construct scientifically correct microscopic models of friction and lubrication.

**Keywords:** Friction, Microscopic, Students' Conceptions, physics education research, transfer of learning.

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## INTRODUCTION

Numerous studies have documented students' ideas about the particulate or microscopic nature of matter. [1] The importance of such studies can't be overemphasized. We are at the verge of several breakthroughs in nanoscience and technology. Challenging students to think about what is happening at the atomic scale is a great step in advancing the goals of nanoscience education.

We report on students' ideas of friction and lubrication at the atomic level. Friction is a familiar concept to most introductory students and a part of their everyday experience. However, microscopic friction – a hot topic of research, is quite different from macroscopic friction. We believe that it is important that students learn the differences between macroscopic and microscopic friction. To design instruction to help students understand these differences we first investigate their existing ideas about friction.

The research questions of this study are:

- What are the existing models of introductory college students regarding friction and related phenomena at the microscopic level?
- How do students build and use models in explaining common everyday phenomena related to friction?

## METHODOLOGY

Two one-hour semi-structured clinical interviews were conducted per student. A total of 11 students enrolled in algebra-based introductory physics classes were interviewed. Almost all students were life science majors. We pilot-tested our protocol with other educational researchers and two students and revised the protocol based on their feedback.

We began by asking students to slide their fingers across a wooden block and sketch the surface starting at the macroscopic scale and zooming in progressively to smaller length scales. Most of the students eventually realized that zooming in would get them to the atomic level. However, they were unsure of the length scale at which that would occur.

Follow-up questions explored ideas about:

- Cause of friction at the atomic level,
- Differences between kinetic and static friction,
- Effect of surface roughness on friction,
- Effect of gravity on friction, and
- Lubricating mechanism of oil.

The interviews were videotaped. We used phenomenographic analysis [2, 3] as per which students' responses are grouped into naturally occurring catego-

ries based on their quotes. A second layer of analysis combined the categories of responses across different questions to generate themes.

## RESULTS & DISCUSSION

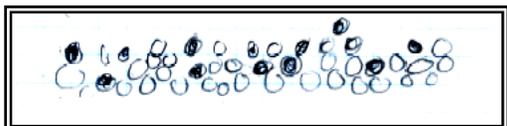
### Cause of Friction at the Atomic Level

Students were asked to pull a wooden block over a plank. Interviewees talked about friction when explaining why they needed a finite force to start the block moving. Follow-up questions probed students' ideas about the causes of friction at the atomic level. Below are category descriptions.

#### *Intertwining / Interlocking Model*

Five of the eleven interviewees explained that friction is the force needed to pull an atom over the bumps due to the interlocking or intertwining of atoms. Figure 1 shows an interviewee's sketch.

*"when you set it [the block] on top, it kind of settles in ...like goes into a neutral energy state. When I try to move it I got to pull them out so there will be some friction because there will be some particles getting intertwined (fingers of hand intertwining)."*

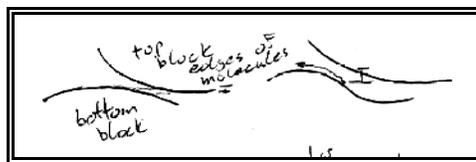


**FIGURE 1.** The atoms of the wooden block (shaded) interlock with the atoms of the table top (not shaded).

#### *Rubbing / Sliding / Hitting Model*

Three interviewees explained that atoms rubbing or hitting against each other is the reason for the finite amount of force needed to start the wooden block moving (see Figure 2)

*"They (atoms) don't mesh together at all. They just sit on top of one another...they are touching but they don't interact any more than just the physical contact... one of them is moving and one of them isn't moving so they rub together."*



**FIGURE 2.** The atoms of the wooden block rub against the atoms of the tabletop.

#### *Bonding Model*

According to two of the interviewees, friction is due to the force needed to break the bonds between surfaces that come into contact.

*"So when it is just sitting, these two would form some sort of bond which make them stick close together...you kinda have to overcome these little bonds enough to break them."*

### Why Static Friction > Kinetic Friction

In explaining why static friction is greater than kinetic friction the following categories emerged.

#### *Changing Downward Force*

One of the interviewees expressed the view that friction is due to the downward force that presses one surface onto the other. When the surfaces begin to move, this downward force decreases causing friction to decrease.

*"When it is at rest there's more pressure between the atoms...when it starts moving you have less force pulling down."*

#### *Getting Smoother Model*

According to most of the interviewees, the reason that friction occurs is that the surfaces are rough even at the atomic level. In explaining why static friction is greater than kinetic friction, one of them described that the surface would somehow get smoother once we started moving one of the surfaces relative to the other.

*"I would think that it seems like when it is just sitting there, the surfaces are somehow interacting and making one another almost more rough. The way this works basically is it is more rough when it wasn't moving than when it was."*

### *Broken Bonds Model*

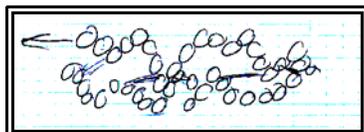
This explanation was provided by a student who initially said that static friction between the two surfaces is the force needed to overcome the bonds between the atoms of the surfaces.

*“When it has started moving, let’s say they might not have enough time to form that (bond)... So there’s less number of bonds to be broken.”*

### *Skimming Over the Top Model*

This explanation was provided by most of the interviewees who previously described friction as due to the intertwining or interlocking of atoms. Once the block has started moving the atoms of the block just skim over the atoms of the other surface (Figure 3).

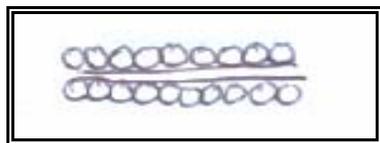
*“It already got some initial velocity... We pulled off the atom. There’s still gonna be resistance between the two at the molecular level... but not as much because they are not settled in. When you’re moving it they’re gonna be not as intertwined.”*



**FIGURE 3.** The atoms of the wooden block skim over the top atoms of the table surface once it is in motion.

### **Friction on Perfectly Flat Surfaces**

When asked to visualize two perfectly flat surfaces, students typically drew a sketch similar to Figure 4.



**FIGURE 4.** Atoms line up on perfectly flat surfaces.

Students were asked whether friction would still exist between these two perfectly flat surfaces. Their responses could be categorized as follows.

### *Mechanical Interactions Model*

According to five (5) of the students interviewed there will still be friction because we still have atoms that interact (mechanically) even when surfaces become perfectly flat.

*“There would still be friction because we still have atoms sliding past one another and also hitting each other.”*

### *Gravity Model*

This is the explanation by the student who earlier had the “changing downward force model” in explaining why static is greater than kinetic friction.

*“There will still be friction because there is still force of gravity pushing down. Gravity has to be zero for friction to be zero.”*

### *Electrical Interactions Model*

Below is a student’s description of what happens when two perfectly flat surfaces slide past one another:

*“There is still friction because of electrical interactions.”*

### **Why Oil Reduces Friction**

In explaining the lubricating mechanism of oil, students’ explanations could be categorized as follows.

### *Ball Bearing Model*

According to five (5) students, oil reduces friction just like ball bearings.

*“.. it might be possible that they move past one another easier, but it could be that oil molecules roll.”*

### *Weaker Bonds Model*

With oil in between the surfaces, one of the students thinks that friction will be less because there is a weaker bond to break.

*“maybe they don’t exhibit as much intermolecular bonds between each oil molecule than between oil and wood molecules so they can move past one another.”*

### *Floating Model*

Four (4) students who expressed this view said that friction is reduced because atoms of oil provide a floating barrier for the atoms of the wooden block.

*“liquid ... will help separate these bumps and valleys such that they don't have to interact with the full scale interaction.”*

## Emergent Themes

Two themes emerged from the second layer of analysis of the variations in the students' descriptions of friction and lubrication -- mechanical and chemical interactions.

### *Mechanical Interactions*

We observed the persistence of students' responses that friction is simply due to mechanical interactions of the atoms. When they were asked to explain what causes microscopic friction most students alluded to the interlocking/intertwining or rubbing/hitting model. These descriptions are not surprising because these students had learned about friction only in the macroscopic context and had not dealt with friction at the atomic level. Therefore, these students appear to apply their macroscopic ideas to explain friction at the microscopic level. For these students friction is either the force needed to pull an atom over the bumps due to intertwining/interlocking of atoms or the force due to the rubbing/sliding of an atom past another atom. When the five students who expressed these views were asked what happens if the surfaces become atomically smooth they said that friction persists because atoms still physically rub against each other. Similarly, when students were asked to explain why oil reduces friction, most of them likened the oil atoms to ball bearings rolling between the atoms of the two solid surfaces. These explanations of friction and lubrication are clearly based on their experience with macroscopic friction. Thus, for most students, what is true macroscopically must also be true microscopically. This general result is consistent with previous research on student understanding of the microscopic world [4].

### *“Bonding”*

For some of the students, microscopic friction is due to the force needed to break the bonds between the atoms of surfaces that come into contact. When these students were asked to explain why kinetic friction is less than static friction they said that there are fewer bonds to break once the other surface is set in motion than before it begins to move. Similarly when asked to explain what happens when there is oil in between two surfaces, one of these students believed that fric-

tion is reduced because it's the weaker bond between oil and wood that needs to be broken instead of the bond between wood and wood

## FUTURE DIRECTIONS

Based on the results of this study we are currently designing and testing teaching experiments with the goal of helping students adopt microscopic models that are consistent with those used by scientists. The design of teaching experiments is anchored on the tenets of constructivist conceptual change [5] -- first establish students' existing knowledge and then either modify or build on it to promote conceptual change. The above results have made us aware of the ideas of friction and lubrication that students bring into the classroom. Through the use of discrepant events we will enable students to challenge some of their existing ideas. Alternatively, through reinforcement activities we will help students build on and refine other productive ideas. Thus, we will facilitate students' knowledge construction processes. The teaching experiments can inform us of effective instructional strategies that can contribute to knowledge reconstruction by students.

## ACKNOWLEDGMENTS

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