Refining Students' Ideas of Microscopic Friction: A Case Study with Two Students[$]

Edgar G. Corpuz and N. Sanjay Rebello

Department of Physics, 116 Cardwell Hall, Kansas State University, Manhattan, KS, 66506-2601

Abstract. Teaching interviews were conducted with introductory college physics students to investigate the dynamics of their knowledge construction in the context of microscopic friction. Specifically, we investigated the extent to which scaffolding activities influenced the activation of students' prior knowledge and its impact on their knowledge construction. In this paper we present the scaffolding activities and describe how these experiences subsequently influenced the refinement of prior ideas of two students regarding microscopic friction. Results imply that the extent to which the students utilize the sequence of scaffolding activities in refining their previous ideas greatly depends on their individual zone of proximal development.

Keywords: friction, microscopic, students' conceptions, physics education research.
PACS: 68.35, 01.40Fk

INTRODUCTION

Our previous research [1] showed that students' mental models of friction at the atomic level are significantly influenced by their macroscopic ideas. But can we build on these ideas in order to help student adopt better models of explanation for microscopic friction? This research aims to design instructional experiences that facilitate refinement of students' ideas of microscopic friction building on their prior knowledge and experiences. We ask:

- What scaffolding – cues, hints, etc. – can help students refine their knowledge of atomic friction?
- To what extent can they utilize this scaffolding to refine their prior knowledge of atomic friction?

THEORETICAL FRAMEWORK

We adapt the Vygotskian [2] social constructivist view that learning occurs within a Zone of Proximal Development (ZPD) facilitated by interactions with more capable individuals through scaffolding. [3] We utilized several scaffolding activities, including conceptual change strategies, [4] to enable students to refine and extend their models of microscopic friction.

METHODOLOGY

The teaching interview [5] or experiment [6] is used to investigate the dynamics of conceptual change. The researcher-interviewer facilitates students' construction ideas through pedagogically appropriate scaffolding activities which also provided a context to investigate students' *in situ* knowledge construction.

Students began by feeling the surface of a wooden block and sketching it at the atomic level (<u>Activity #1</u>). This activity explicated their understanding of atomic roughness. Here atomic roughness pertains to the alignment of surface atoms. Atomically smooth surfaces are represented by atoms lining up. Next, they predicted and compared the frictional force on the wooden block dragged on sandpaper versus a smooth plank and explained their findings based on their previous sketch (Activity #2). They represented their current understanding by sketching a graph of Friction vs. Roughness of the sliding surfaces (Activity #3). Students were then introduced to a gauge block with smooth and rough surfaces. They predicted that it would be easiest to drag the smooth surfaces across each other. But, tests showed that friction was greatest between the smooth surfaces.

[$] Supported by NSF grant REC-0133621

Table 1. Ideas Generated by Jenny and Joe from the Scaffolding Activities

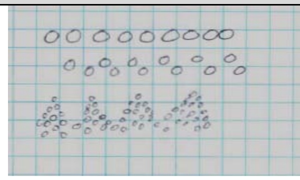
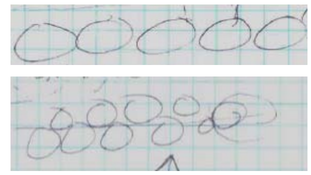
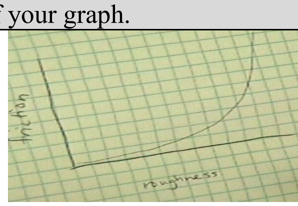
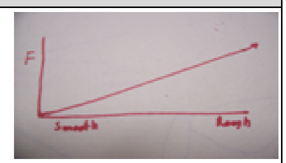
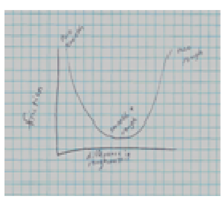
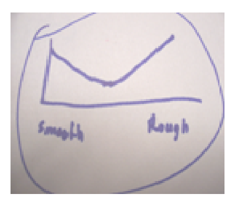
JENNY'S IDEAS	JOE'S IDEAS
ACTIVITY 1: FEELING & SKETCHING OF SURFACES **Sample Questions/Instructions**: ■ Slide your fingers across the surfaces. ■ Please sketch what the surfaces would look like at the level where you see the atoms.	
Smooth surface is represented by atoms lining up while rough surface is represented by atoms arranged in an up and down pattern. 	Smooth surface is represented by atoms lining up while rough surface is represented by atoms arranged in an up and down pattern. 
ACTIVITY 2: WOODEN BLOCK DRAGGED ACROSS WOODEN PLANK & SANDPAPER SURFACE **Questions:** • Could you please explain what you observed? • Why is the force greater on the sandpaper than on the wooden plank?	
• More friction on sandpaper because it is rougher. • Friction explained in terms of catching of ridges. *"Ridges are catching on each other… not much ridge on smoother surface to catch on so friction is less."*	• More friction on sandpaper because it is rougher. • Friction explained in terms of atomic arrangement. *"Block's atoms fit down more into the atoms of the sandpaper so there's more friction."*
ACTIVITY 3: GRAPHING OF FRICTION VS SURFACE ROUGHNESS **Questions:** • Please sketch how the friction force varies with the roughness of both surfaces. • Explain the details of your graph.	
Friction varies with roughness as shown. 	*"Pretty linear relationship. As the roughness increases so does the friction. And I suppose that it could be like not linear, but in any case as one increases the other also increases."* 
ACTIVITY 4: METAL BLOCKS ACTIVITY **Questions/Instructions**: • Please slide your fingernails across the surfaces of the metal blocks. • In which case (smooth vs smooth or smooth vs rough) will you have more friction?	
<u>Prediction & Explanation</u>: "*More friction between the smooth and rough sides than in the smooth and smooth sides. The friction decreases for smoother surfaces*."	<u>Prediction & Explanation</u>: *"More friction on the rough side than the smooth sides. The coefficient of friction between the rough side is greater than the smooth sides."*
ACTIVITY 4: METAL BLOCKS ACTIVITY **Questions/Instructions:** • Slide the smooth surfaces together then the smooth on the rough surface. • Explain your observation.	
<u>Observation & Explanation</u>: *"More friction between the smooth and smooth sides. The metal blocks are magnets."*(She later abandoned this idea after testing its magnetic properties and realizing it was not so.)	<u>Observation & Explanation</u>: "*Smoother one has more friction than the rougher one… the surface that feels smoother actually has more interaction between the two surfaces producing greater friction."*
ACTIVITY 5: PAPERS ON TRANSPARENCY ACTIVITY **Questions/Instructions:** • Predict in which case you will have more friction when the uncrumpled and crumpled piece of papers are slid across the transparency.	
<u>Prediction & Explanation:</u> *"I think this one (uncrumpled paper) will produce more friction. Well I've worked with transparencies before and I know that they can stick to sheets of paper.*	<u>Prediction & Explanation:</u> *"I think this (uncrumpled) one would because it is like the metal blocks. It is smooth so it will create more contact, whereas here the points touching will be less."*

Table 2. Ideas Generated by Jenny and Joe (continuation…)

JENNY'S IDEAS	JOE'S IDEAS
ACTIVITY 5: PAPERS ON TRANSPARENCY ACTIVITY **Question/s:** • Slide the crumpled and flat sheet of paper across the transparency. • What did you observe?	
Observation & Explanation: *"More friction with the uncrumpled paper. Well, with the uncrumpled sheet of paper, there's more contact ….the crumpled papers they will just be touching where the ridges will go down."*	Observation & Explanation: *"This (uncrumpled paper) one has more friction. There's more surface area that actually touch with the transparency than this (crumpled) one. Atoms of the paper have more protons than electrons so it is positive while the atoms of the plastic sheet have more electrons than protons so it is negatively charged and opposite attract that would produce more friction."*
ACTIVITY 5 : SLIDING OF PAPERS ACROSS THE TRANSPARENCY RUBBED WITH FUR **Question/s:** What would happen to the friction force if we rubbed the transparency with the fur?	
"The friction would be more because they will stick more. I'm not sure why they stick"..	*The paper is positively charged and this (transparency) can be negatively charged because we rubbed it with fur and gave it electrons and that would create an attraction between the transparency and the paper and that would add to the friction force.*
ACTIVITY 6: RELATING THE METAL BLOCKS AND PAPERS ON TRANSPARENCY ACTIVITIES **Question/s:** How would you relate the one you did on the metal blocks and the one with the papers on transparency?	
"Well, more surface contact here (smooth sides) and less on this (rough) side. Because it is a smoother surface (uncrumpled paper). It's more similar to the surface of this (smooth side of the metal block)."	*"For two smooth metals, if one is positive and one is negative then they would attract each other, which would increase the friction. Then on the rough one, there will be less attraction because you have less number of atoms close to each other."*
ACTIVITY 7: REVISITING THE GRAPH OF FRICTION FORCE VS ROUGHNESS **Question/s:** • Do you still go with the graph that you have drawn earlier? • If you are to modify your graph what would it look like? • Explain the details of your graph.	
"Well, if you have two smooth surfaces there's a lot of friction and when you have two rough surfaces rubbing against each other again there will be a lot of friction. But with two with medium roughness, there's not much." 	*The smoother it is the more friction because there's more surface area of contact, and there would be more electrical interactions… But there will be a point (refers to the right hand side of the graph) where the electrical interactions would be overwhelmed by the weight, where the friction will increase again."* 

Students resolved this cognitive dissonance by dragging two identical sheets of paper – crumpled and uncrumpled across a transparency rubbed with fur (Activity #5). The papers and transparency activity activated students' ideas of charges and the electrical origin of atomic friction. Students were then asked to relate this activity with the metal blocks activity (Activity #6) and revisit their sketch of Friction vs. Roughness (Activity #7). They combined their ideas of friction explored thus far and applied them to the gauge block and transparency activities to explicate the factors that influenced friction: atomic contact area and strength of electrical interaction.

RESULTS AND DISCUSSION

Tables 1 & 2 show the details of knowledge construction by Jenny and Joe (not their real names). Jenny was enrolled in first-semester algebra-based physics and had no prior instruction in electricity. Joe was enrolled in second-semester calculus-based physics and had prior instruction in electrostatics.

Thus these students were clearly in different zones of proximal development. We selected these two students for our case study analysis from among a total of 16 students who were interviewed – eight of whom were enrolled in first semester algebra-based physics and the other eight in calculus-based physics. We selected these two students for this case study because they were representative of the other interviewees in the way in which they progressed through the activities described below.

It can be seen from the table (Activity #1) that both students associate smooth surfaces and rough surfaces with aligned and misaligned atoms respectively. In explaining the cause of friction when the wooden block was dragged along wood/sandpaper surfaces (Activity #2), Jenny used the "catching of ridges" explanation while Joe use the "fitting in of atoms" explanation. When asked to graph the friction force versus the roughness of the sliding surfaces (Activity #3), both students associated increasing force with increasing roughness. We then refined these ideas by having students do Activities #4 through #7.

The scaffolding activities (#4 - #7), helped Jenny and Joe construct the idea that friction is dependent on the area of contact. However, the same sets of scaffolding activities led Joe to explain his observations in terms of charges. Although Joe's explanations are not scientifically accurate we believe that the activities made him aware of the role of electrical interactions in microscopic friction. It is apparent that Joe transferred what he learned from his previous class in electrostatics. The idea that microscopic friction is dependent on atomic contact area and that it is due to electrical interaction is consistent with the ideas of some nanotribologists. [7]

With regard to the variation of friction with surface roughness the scaffolding activities helped the students realize that for microscopically smooth surfaces the friction force increases with decreasing roughness (left hand side of U-shaped graph) but for macroscopically rough surfaces the friction force increases with increasing roughness (right hand side of the U-shaped graph). Both students realized that friction would be higher for microscopically smooth surfaces due to a larger contact area. Joe also stated that the friction was higher due to greater electrical interactions.

With respect to the variation of friction with surface roughness and the role of contact area, it is apparent that the two students are at the same ZPD. With respect to the idea that friction is due to electrical interactions the students are in different ZPDs. For Joe, the scaffolding made him aware of the role of electrical interactions in friction at the microscopic level. However, this understanding appeared to be beyond Jenny's ZPD, probably because she had not studied charges in first-semester physics.

LIMITATIONS OF STUDY

Case studies, such as this are by nature limited in their sample size. Therefore, we acknowledge that one must be cautious in generalizing the case study to larger groups. However, we do believe that the small-grained, microgenetic analysis afforded by this case study provides some interesting and useful insights into how the student's utilize scaffolding activities to refine their ideas about microscopic friction, and the factors that mediate this process.

CONCLUSIONS

In this study we have demonstrated that through the aforementioned sequences of activities it is possible to facilitate the refinement of students' ideas of microscopic friction. The extent to which students can utilize this scaffolding to refine their ideas and construct the target ideas depends upon their individual zone of proximal development. Students who have knowledge of electrical interactions were more likely to consider electrical interactions between charges as being the origin of atomic friction.

REFERENCES

1. Corpuz, E.G. and N.S. Rebello. *Introductory College Physics Students' Mental Models of Friction and Related Phenomena at the Microscopic Level*. in *Annual Meeting of the National Association for Research in Science Teaching*. 2005. Dallas, TX.
2. Vygotsky, L.S., *Mind in Society: The development of Higher Psychological Processes*. 1978, Cambridge: Harvard University Press.
3. Bruner, J.T., *Vygotsky's Zone of Proximal Development: The Hidden Agenda*, in *Children's Learning in the Zone of Proximal Development*, B. Rogoff and J. Wertsch, Editors. 1984, Jossey-Bass.
4. Strike, K.A. and G.J. Posner, *A revisionist theory of conceptual change*, in *Philosophy of science, cognitive psychology, and educational theory and practice*, R.A. Duschl and R.J. Hamilton, Editors. 1992, State University of New York Press: New York, NY.
5. Steffe, L.P. and P.W. Thompson, *Teaching experiment methodology: Underlying principles and essential elements*, in *Research design in mathematics and science education*, R.K. Lesh, A. E., Editor. 2000, Erlbaum: Hillsdale, NJ.
6. Engelhardt, P.V., et al. *The Teaching Experiment - What it is and what it isn't*. in *Physics Education Research Conference, 2003*. 2003. Madison, WI.
7. Robbins, M.O. and J. Ringlein, *Understanding and illustrating the atomic origins of friction.* American Journal of Physics, 2004. **72**(7): p. 884-891.