STUDENTS' CONCEPTUAL DEVELOPMENT IN THE CONTEXT OF MICROSCOPIC FRICTION: A CASE STUDY WITH TWO STUDENTS

In this study we investigated the progression of student ideas as we try to scaffold their knowledge construction/reconstruction of microscopic friction. We conducted teaching interviews with twenty (20) introductory college physics students in order to investigate how they dynamically construct/reconstruct their knowledge. In this paper we present the case of two students whose conceptual progressions closely resemble that of the other students interviewed. We present the different ideas that students generate from the different scaffolding activities and describe how these ideas dynamically change during the teaching interview. Our results suggest that students can be led to make a more scientific explanation of an unfamiliar phenomena (i.e. microscopic friction) by providing them scaffolding that activates their prior knowledge. Results of our study will provide a baseline data for the development of instructional material geared towards helping students construct a better explanation of microscopic friction.

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Introduction

Research (Anderson, 1990; Corpuz & Rebello, 2005) has shown that students' explanation of a phenomenon at the microscopic level is significantly influenced by their macroscopic ideas. We believe that there is a need to make students realize the disparity between microscopic and macroscopic friction. In this study we try to influence students' construction of more scientifically accepted explanations of microscopic friction by providing them scaffolding activities. Specifically we try to address the following research questions:

- What ideas do students generate out of the different scaffolding (activities, hints, cues and other prompts) provided to them?
- To what extent do students utilize these scaffolding and their prior knowledge in reconstructing more scientific explanations of microscopic friction?

In this research we adapt the Vygotskian (Vygotsky, 1978) social constructivist perspective that learning is a dynamic process where students construct new ideas and skills and reconstruct previous knowledge through interactions with their environment. Central to the Vygotskian perspective of constructivism is the idea of the existence of the *zone of proximal development (ZPD)*. The zone of proximal development is the distance between what an individual can accomplish on his/her own and what he/she can accomplish when assisted by more capable peers or adults. To optimize students' learning within their zone of proximal development, they can be provided with appropriate scaffolding (Bruner et al. 1976).

We utilized several scaffolding activities to enable students to refine and extend their models of microscopic friction during the teaching interviews (Engelhardt, Corpuz, Ozimek, & Rebello, 2003) and show how these influenced students' knowledge construction. Our conceptual change strategies integrate cognitive conflict to scaffold their knowledge construction and reconstruction. (Scott, Asoko, & Driver,1992; Strike & Posner, 1992)

Methodology

The teaching interview (Engelhardt et al., 2003) is an adaptation of the teaching experiment (Steffe & Thompson, 2000) that has been used to investigate the dynamics of conceptual change. The researcher-interviewer facilitates students' construction of target conceptions through pedagogically appropriate scaffolding. Listed below are the target conceptions based on interviews with content experts, initial research on students' mental models and literature on microscopic friction. (Robbins & Ringlein, 2004)

- Friction is due to electrical adhesion of atoms.
- Friction force is dependent on the microscopic contact area
- Friction force varies with roughness as shown in Figure 1. When two surfaces become microscopically smooth the friction would be high because there will be more areas of interactions.
- Atomic friction is described by the equation

$$f = \mu N + cA \qquad (1)$$

where 'c' is the force needed to overcome electrical interactions between atom pairs and 'A' is the atomic area of contact between the surfaces (atom pairs that come into close contact).

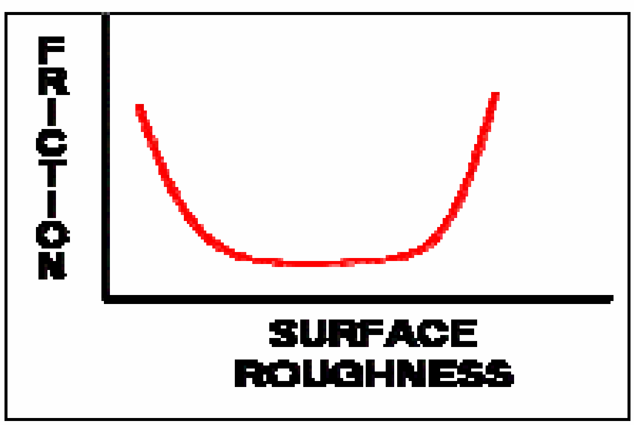


Figure1. Friction Force vs. Roughness of Both Surfaces

A sequence of activities provided a context for interactions with the interviewer-researcher. Students began by feeling the surface of a wooden block and sketching it at the atomic level (Activity #1). This activity explicated their understanding of atomic roughness. Next, they predicted and compared the frictional force on the 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. surface roughness (Activity #3). Students were then introduced to two metal gauge blocks (Activity #4) that each had a smooth polished surface and other rough surfaces. Students predicted surfaces that would be easiest to drag across the other and tested their predictions which showed that friction was the greatest between the smooth surfaces. They attempted to explain this discrepant event by revisiting the atomic-level sketch of the surfaces. To resolve the cognitive dissonance, students compared the difficulty in dragging two identical sheets of paper – crumpled and uncrumpled across a transparency (Activity #5). This activity provided students with a clue about the electrical origin of atomic friction, which they were asked to explain in the gauge block activity (Activity #6) and revisit their sketch of friction vs. surface roughness (Activity #7). They then 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 area of contact ‘A’ and strength of electrical atomic adhesion ‘c’ (Activity #8) and were subsequently led to come up with a mathematical model of microscopic friction. The notion that friction should depend upon the area of contact is contrary to what students may have learned in introductory physics and two other activities (not discussed here) that addressed this discrepancy. The above activities were not ‘standalone.’ Consistent with Vygotskian social constructivism, the students constantly interacted with the interviewer-researcher to facilitate the construction of their ideas.

The Informants

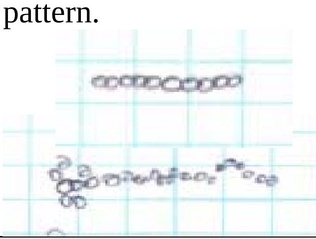
Twenty (20) students who were currently enrolled in introductory physics courses at the time of this study participated in two one-hour individual teaching interviews. In this paper, we document how two of those students (Steve & Rose) dynamically constructed/reconstructed their ideas as they were provided with scaffolding activities. Their conceptual development closely resembles that of the other students interviewed. Steve was taking first semester algebra-based physics while Rose was taking second semester calculus-based physics and had prior instruction in chemistry.

Results and Discussion

Tables 1, 2, 3 and 4 present the detailed results of knowledge construction by Rose and Steve. In Table 1 we can see that both students seemed to provide the same explanations about friction. It was harder to pull the wooden block across the sandpaper because the surfaces are rougher. And that if the surfaces are made smoother the friction will decrease and eventually approach zero as depicted by the graphs in Table 1.

As can be seen in Table 2, the gauge block activity put the two students in a state of cognitive dissonance in that their observations contradicted their predictions. At this point of the teaching interview the students realized that their current model is not enough to explain their observations. Although Rose realized right away that there are other forces that affect friction, she can’t actually tell what is causing the difference. To resolve the conflict we have them do the paper and transparency activity (Table 3). This scaffolding activity helped the two students construct the idea that friction is dependent on the actual contact between two surfaces.

Table 1: Scaffolding inputs and ideas generated by Steve and Rose

<table>
<tr><td colspan="2">ACTIVITY 1: FEELING & SKETCHING OF SURFACES
Sample Questions/Instructions:
Please sketch what the surfaces would look like at the level where you see the atoms.</td></tr>
<tr><th>Steve's Ideas</th><th>Rose's Ideas</th></tr>
<tr><td>Smooth surface is represented by atoms lining up while rough surface is represented by atoms arranged in up and down pattern.
</td><td>Smooth surface is represented by atoms lining up while rough surface is represented by atoms arranged in up and down pattern.

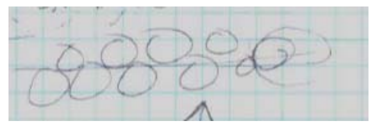
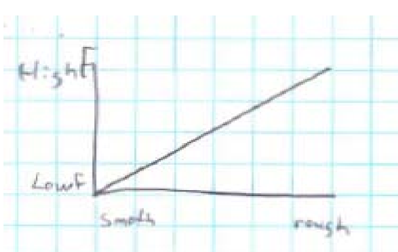
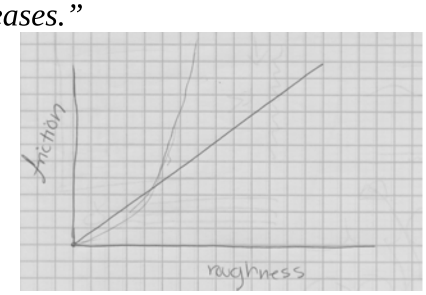
</td></tr>
<tr><td colspan="2">ACTIVITY 2: WOODEN BLOCK DRAGGED ACROSS THE WOODEN PLANKAND SANDPAPER SURFACE
Questions:
• Could you please explain what you observed?
• Why is the force greater on the sandpaper than on the wooden plank?</td></tr>
<tr><th>Steve's Ideas</th><th>Rose's Ideas</th></tr>
<tr><td>"More Newtons of force to pull it on the sandpaper than on here (wooden plank) because it is rougher. It was harder to pull across because the bumps will catch with each other."</td><td>"It was easier to drag the wooden block across the wooden surface than on the sandpaper because the sandpaper is a lot rougher and it has like bigger ridges"</td></tr>
<tr><td colspan="2">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.</td></tr>
<tr><th>Steve's Ideas</th><th>Rose's Ideas</th></tr>
<tr><td>"The rougher the surface, the higher the friction becomes. The smoother it is, the smaller the friction."

</td><td>"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."

</td></tr>
</table>

Table 2: Scaffolding inputs and ideas generated by Steve and Rose (continued)

ACTIVITY 4: METAL BLOCKS ACTIVITY **Questions/Instructions**: • Please slide fingernails across the surfaces of the metal blocks. • Sketch how the surfaces would look at the level where you see the atoms. • In which case (smooth vs smooth or smooth vs rough) will you have more friction?	
Steve's Ideas	**Rose's Ideas**
"More friction on this one (rough side of metal block) because it is rougher."	*" You're gonna have more friction with the rough surface than on the smooth surface because the rough surface would resist the movement more because you have like bigger places to catch on so it will get stuck more easily."*
ACTIVITY 4: METAL BLOCKS ACTIVITY **Questions/Instructions:** • Slide the smooth surfaces together, then the smooth on the rough surface • Explain your observation.	
Steve's Ideas	**Rose's Ideas**
"It feels like there's less friction on the surface that feels rougher. I don't know. I don't have any idea why."	"There are *other forces that would affect friction. You might have cohesion because the materials kind of stick together…You have some type of atomic forces that make them stick together."*

Moreover, the gauge block activity led Rose to the idea that friction at the atomic level is due to electrical interactions (bonding of atoms). In the case of Steve this scaffolding provided him hints that his present model is not enough so there is a need for him to reconstruct it. The metal blocks and papers & transparency activities helped him construct the idea that friction is dependent on the actual contact between two surfaces. However, it did not facilitate his thinking of electrical interactions as the cause of friction.

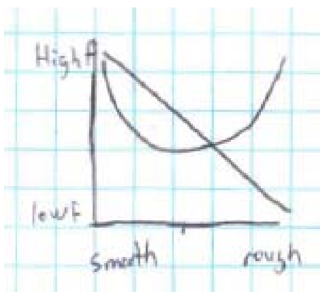
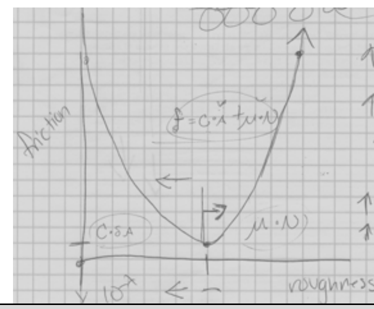
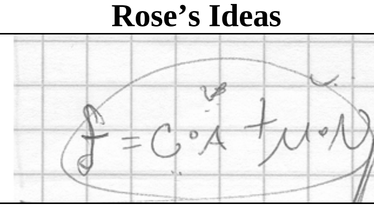
In Table 4 we can see how the two students reconstructed their ideas about how friction varies with surface roughness and the factors that come into play when surfaces become very smooth. The different scaffolding activities successfully led them to construct a model consistent with the target model that friction force varies with the relative roughness of the surfaces as depicted in Figure 1.

The progression of students' ideas is mapped in Figure 2. With respect to the target ideas of 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. However, with respect to the target idea that friction is due to electrical interactions and the mathematical model in equation (1) the students are in different ZPDs. For Rose, the scaffolding provided was productive in

Table 3: Scaffolding inputs and ideas generated by Steve and Rose (continued)

ACTIVITY 5: PAPERS ON TRANSPARENCY ACTIVITY **Questions/Instructions:** Predict in which case will you have more friction when the flat sheet and crumpled piece of papers are slid across the transparency.	
Steve's Ideas	**Rose's Ideas**
"Probably this (flat sheet) because like electrostatic charges will cling to it more, I think than it would on this one (crumpled)."	*"On the scale that we are considering, this one would have more friction because it has more areas touching each other. For the crumpled paper if you lay it down there's not much surface area in contact with the other surface. "*
ACTIVITY 5: PAPERS ON TRANSPARENCY ACTIVITY **Questions:** • Slide the crumpled and flat sheet of paper across the transparency. • What did you observe? • Was that what you predicted?.	
Steve's Ideas	**Rose's Ideas**
"There's more on this one because there's more touching. In this one because it is crumpled up, it's not lying flat on it. I'd say the greater the surface area the more friction it would have."	*"That one has more friction because there's more surface area touching. "*
ACTIVITY 6 : SLIDING OF PAPERS ACROSS THE TRANSPARENCY RUBBED WITH FUR **Question:** What is causing the friction between the two surfaces?	
Steve's Ideas	**Rose's Ideas**
"It's static electricity or something. When you rub this it kind of creates a static charge and it will cling to it (paper)."	**Not Necessary**
ACTIVITY 6: RELATING THE METAL BLOCKS AND PAPERS ON TRANSPARENCY ACTIVITIES **Questions:** How would you relate the one you did on the metal blocks and the one with the papers on transparency?	
Steve's Ideas	**Rose's Ideas**
"There's more friction on the flat sheet because the more surface areas touching and that would be the same for that one too (smooth metal block surface). There's more surface area touching on this one (smooth side of the metal block) than on this side here (rough side of the metal block)."	*"With these two (smooth sides of metal block) you have more surface area touching each other and so more surface area means more contact between the little bumps or little microscopic atoms or whatever. And so more chances for them to interact.*

Table 4: Scaffolding inputs and ideas generated by Steve and Rose (continued)

<table>
<tr><td colspan="2">ACTIVITY 7: REVISITING THE GRAPH OF FRICTION FORCE VS ROUGHNESS
Questions:
• Do you still go with the graph that you have drawn earlier?
• If you are to modify your graph what would it look like?
• What happens when surfaces become very smooth?
• What happens when they are very rough like the sandpaper?</td></tr>
<tr><th>Steve's Ideas</th><th>Rose's Ideas</th></tr>
<tr><td>" The smoother the objects are, just like what we had there (points to metal blocks), the smoother the greater the friction… when it gets rougher like that (points to sandpaper) the friction would be high too."

</td><td>" If you have high roughness you will still have high friction… when you have perfect smoothness, they would bond back together and you will have infinite friction. So, you will have a nice little parabola."

</td></tr>
<tr><td colspan="2">ACTIVITY 8: MATHEMATICAL MODELING
Questions:
• How would you compute the friction force between the wooden block and the sandpaper surface?
• If we go back to your sketch of the flat sheet of paper and transparency, what would be the factors that we need to consider?
• Let us zero in on your sketch for the smooth metal blocks. If we represent c as the force needed to overcome the interaction between pairs of atoms, how would you calculate the total force needed to move one surface over the other?
• In which part of your graph does μN dominate and which part of your graph does cA dominate?
• What factors come into play in the lowest portion of your graph?</td></tr>
<tr><th>Steve's Ideas</th><th>Rose's Ideas</th></tr>
<tr><td>Not Completed</td><td></td></tr>
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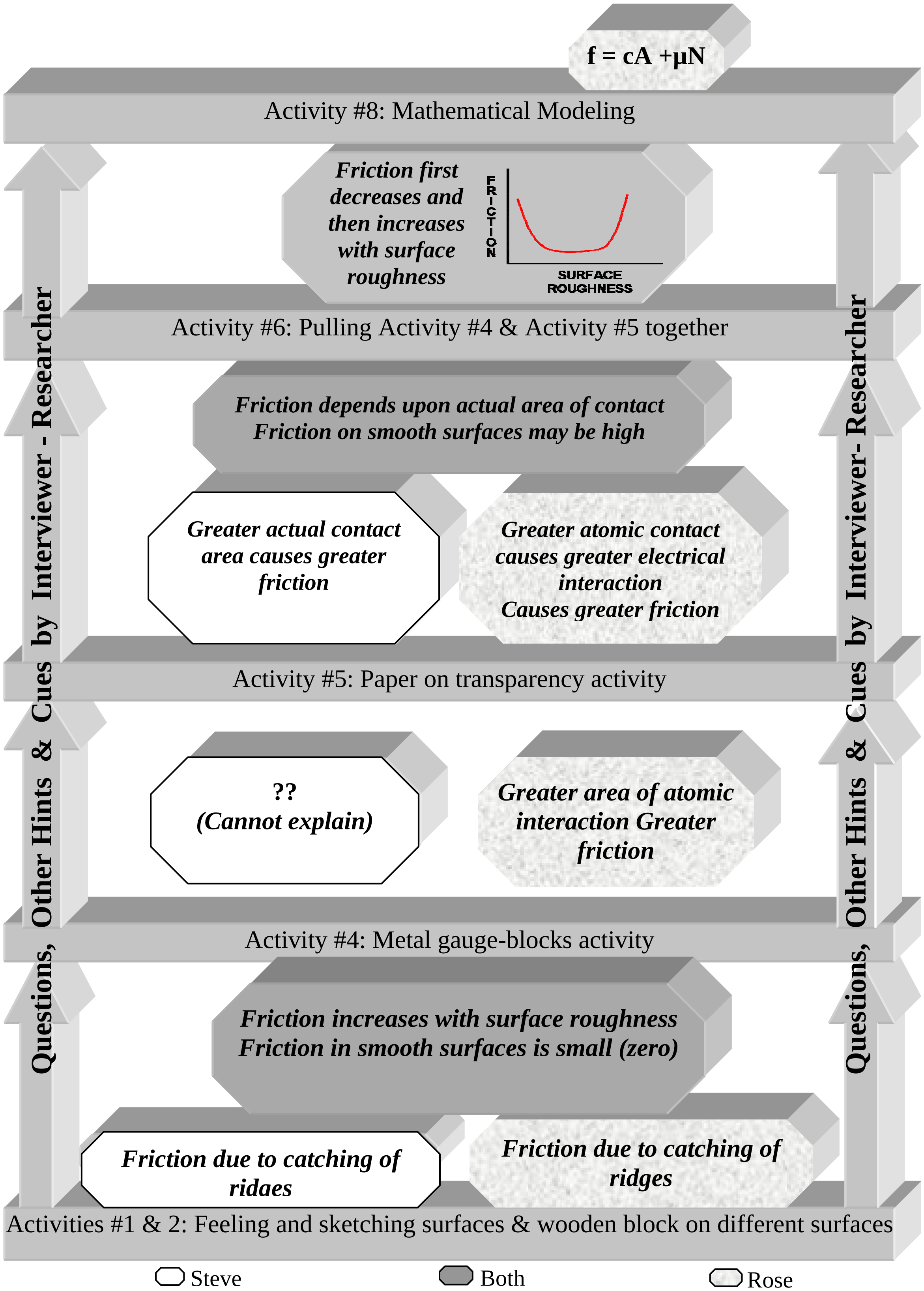

Figure 2. Conceptual Development of Steve and Rose via the Scaffolding Activities

facilitating construction of a model given by (1). This is probably because he already had learned that

$$f = \mu N \qquad (2)$$

prior to the interview and was also familiar with electrical interactions. The activities with the gauge blocks and transparency helped him build on his previous model (2) to arrive at model (1). Steve was not familiar with the friction model given by (2). He was also not familiar with electrostatic interactions before completing this activity. Although the activities helped him construct a model that was qualitatively accurate, he was unable to express this model in terms of equation (1) or understand the electrical origins of friction.

Findings

Through the aforementioned sequences of hands-on and minds-on activities, including cognitive dissonance and resolution, it is possible to facilitate students' construction of a scientifically correct model of atomic friction. Moreover, the extent to which students can utilize this scaffolding to construct the target ideas depends upon their individual zone of proximal development. Students who have knowledge of electrical interactions and friction given by (2) can build on these models through the activities. Students who lack this prerequisite knowledge are unable to do so; however, they are able to construct a qualitative understanding of microscopic friction.

Future Directions

We are currently developing curricular materials based on the results of the teaching interviews which adopt the aforementioned scaffolding inputs. Versions of the material which are optimized to students in the ZPDs discussed above will be developed and pilot-tested.

Acknowledgments

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