Hands-On and Minds-On Modeling Activities to Improve Students' Conceptions of Microscopic Friction

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Abstract. In this paper we discuss the development and validation of hands-on and minds-on modeling activities geared towards improving students' understanding of microscopic friction. We will also present our investigation on the relative effectiveness of the use of the developed instructional material with two lecture formats - traditional and videotaped lectures. Results imply that through a series of carefully designed hands-on and minds-on modeling activities, it is possible to facilitate the refinement of students' ideas of microscopic friction.

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INTRODUCTION

We are currently at the verge of several breakthroughs in nanoscience and technology and we need to prepare our citizenry to be scientifically literate about the microscopic world. An urgent need exists to fill the lacunae of research in the understanding and learning of phenomena at the nanoscale level by all students regardless of their future academic goals. Friction provides a very good context for making students aware of the disparity between the macroscopic and microscopic world.

Our previous research [1] showed that students' mental models of friction at the atomic level are significantly influenced by their macroscopic ideas. For most students, friction is due to meshing of bumps and valleys and rubbing of atoms. The aim of this research is to develop and validate instructional material that facilitates refinement of students' ideas of microscopic friction building on their prior knowledge and experiences. In this paper we present a description of the instructional material developed and its effectiveness in improving students' conceptions about microscopic friction.

The research questions we seek to address are:

- To what extent are the developed materials effective in improving students' conceptions about microscopic friction?
- How does the effectiveness of the developed materials compare with traditional instruction in improving students' conceptions about microscopic friction?

THEORETICAL FRAMEWORK

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

METHODOLOGY

Development of Instructional Module

Teaching interviews [4] were conducted in order to investigate how different modeling activities influence students' conceptual development. The developed instructional module consisted of the hands-on and minds-on activities that were found to be helpful in activating appropriate associations among students during the teaching interviews. We also included questions and hints which scaffolded the construction of productive associations.

In terms of the sequencing of the activities, Karplus' Learning Cycle [5] was adopted. Students were engaged in exploration, concept construction and application activities. The goal of the exploration was to invoke student prior knowledge about friction. The exploration activities included the dragging of a wooden block across a wooden and sandpaper surface and the feeling and sketching of the different surfaces at the atomic level. In this modeling cycle, students' prior ideas about friction were activated.

In the concept construction, students were explicitly required to represent their model using multiple representations. They were asked to sketch a graph of friction vs. surface roughness and talk about what happens to the friction force in different situations. In the application phase, students were given activities or situations where they apply the concepts that they have constructed. This particular application activity involved metal blocks with a smooth surface and other relatively rough surfaces. Here students were asked to make their predictions in which case (smooth on smooth or smooth on rough) they would observe more friction. The application activity produced cognitive conflict since students' predictions differed from their observations.

To resolve this cognitive conflict, students proceeded to the second cycle of the model building process. In the second cycle, students completed the papers and transparency activity for their exploration. In this activity students took a sheet of paper and dragged it across a transparency that had been rubbed with fur. They observed that the paper tends to stick to the transparency and there was resistance to the motion of the paper on the transparency. Later they took the same piece of paper, crumpled it, straightened it out again and dragged it across the same transparency. In this case the paper did not stick and there was no resistance to the motion of the paper on the transparency.

In the concept construction phase, students were asked to explain their observations in the paper and transparency exploration activity. After they explained their observations in terms of the ”real” area of contact they then revisited their previous graph and modified it based on their new experiences with the paper and transparency exploration. They were also asked to reflect on their earlier experiences with the metal blocks and resolve their cognitive conflict. Thus, at the end of the concept construction phase students emerged with a model that accounts for friction in terms of the 'real' area of contact between atoms. The model explains their observations with the metal blocks and the relationship between friction and surface roughness both in the microscopic as well as the macroscopic domains. Students also realize the role of the real area of contact and that friction at the atomic level increases with increasing smoothness. They also understand the role of electrical interactions when talking about friction at the atomic level.

In the application activity students predicted the difference in friction in the two cases: block on its broad side vs. block on its narrow side. The application activity provides a context in which students apply their model that identifies the role of 'real' contact area in a macroscopic context. It allows them to examine how this notion of 'real' area of contact can yield results consistent with the macroscopic result that the force of friction is independent of the area of contact, thus reinforcing the connection between microscopic processes and their macroscopic manifestations.

Validation of Instructional Module

Subject area experts were involved in the content-validation of the materials. The first version of the instructional module was shown to two experts whose research specialization is in surface phenomena. Moreover, these experts had been teaching introductory physics courses for at least six semesters, so they were knowledgeable about the background of targeted students. They examined the instructional module to ensure that the content of the module was scientifically accurate, valid and relevant to the targeted students. The experts' suggestions were minimal, focusing on formatting and inclusion of more pictures. The instructional material was then revised based on the experts' feedback.

Several groups of students were involved in the validation of the developed module. The students typically worked in groups of two or three as they completed the activities. The researcher observed and made field notes of each session. Each session was likewise videotaped with the IRB consent from the students. Post-activity interviews were conducted in order to cross validate the researcher's observations, get students' feedback regarding students' difficulties and confusions and bring forth other issues of concern regarding the implementation of the developed instructional materials.

In addition to completing the post-activity interviews, students were also asked to complete a Likert-scale questionnaire that pertains to the content, appeal, design and difficulty of the developed learning instructional materials. The pilot version of the material was then revised based on the insights gained by the researcher through the observations and the feedback of students during the post-activity interview.

Qualitative Evaluation

Individual as well as groups of two or three students used the developed instructional activities. We kept track of students' conceptual progression by incorporating open-ended questions in the module for them to answer. These reflective open-ended questions were embedded in the module at appropriate points to provide the learner as well as the instructor-researcher feedback about student learning.

In addition to the reflective questions, stopping points were interjected into the module to encourage students to discuss their predictions, observations and thoughts with other members in their group and the instructor. Students were asked to discuss what they were doing in the activities and how these activities influenced their ideas.

Quantitative Evaluation

In addition to the qualitative assessment of student learning we also developed an instrument for quantitative assessment of student learning. To develop the test questions we first identified the learning goals -- target ideas that we wanted students to learn. In ensuring content-related validity of the test, a table of specifications was prepared initially in order to make sure that each target idea that we wanted students to learn was addressed in the test with at least one test item. The table of specifications was shown to two experts in order to cross check whether particular items measured the target ideas. Questions with corresponding distracters were then constructed. The distracters used in each of the items were based on ideas students brought out in the group and individual clinical interviews and teaching interviews conducted in the first two phases of the research. The number of items constructed was constrained by the fact that the test intends only to measure students' understanding on a single topic (microscopic friction). The final version of the test had 10 multiple-choice questions.

The Kuder-Richardson reliability coefficient (KR-20) was 0.67, indicating that the test items were homogeneous, i.e., the test measures the same characteristic of the people taking it. The test is also reliable, i.e., the individual items were producing similar patterns of response in different people. Moreover, it is safe to say that the test is a valid measure of the understanding of microscopic friction in a way that is consistent with the target ideas established for the students.

Gauging the Effectiveness of the Developed Materials

In investigating the relative effectiveness of the developed instructional materials in improving students' conceptions via traditional assessment format, a pre-test post-test control group design was employed. The use of hands-on and minds-on modeling activities were compared with lecture in two formats – traditional lecture and videotaped lecture on microscopic friction. The same ideas that we envisioned students to construct while they did the hands-on and minds-on activities were presented by the instructor in lecture. The time on task for the different groups was almost equal, each being about an hour long. Moreover, the same sets of activities were performed by the instructor in the two lecture formats. The videotaped lecture was conducted by the same instructor who did the traditional lecture.

RESULTS AND DISCUSSION

All of the students participating in this study were enrolled in a conceptual physics course for elementary education majors. There was no statistically significant difference in the performance on class tests and exams between students in the two control groups – videotaped (N = 24), live lecture (N = 56) and the experimental group – activity (N = 66).

Figure 1 shows a comparison between the pre-test and post-test scores of students in the three groups. The three groups also performed very similarly on the pre-test, however their performance on the post-test was markedly different. A two-tailed t-test comparing the pre-test and post-test scores for the activity group indicated a statistically significant difference ($p < 1 \times 10^{-12}$) A similar t-test for the lecture and video group and lecture group showed a statistically significant difference, but the differences were not as significant as the activity group.

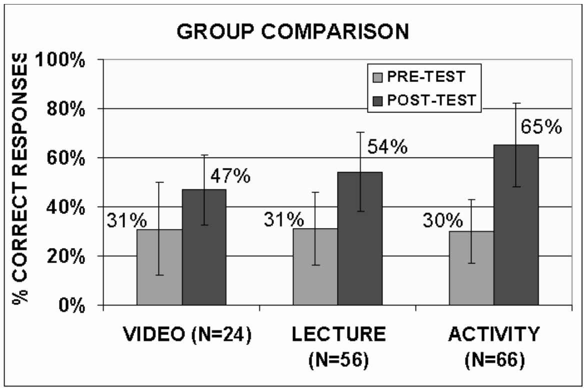

FIGURE 1. Pre-test and post-test scores of the Experimental and Control groups.

In comparing the three groups, we find that the mean pre-test scores are almost all equal to about 30%. The post-test scores, however, are significantly different. A two-tailed t-test comparison between the video and activity groups indicated a statistically significant difference at the $p < 1 \times 10^{-5}$ level of significance. A similar two-tailed comparison between the lecture and activity groups indicated a smaller albeit statistically significant difference at the $p < 5 \times 10^{-4}$ level of significance. Thus, the activity appears to be more effective than either the lecture or the videotaped lecture in improving student conceptions of friction as measured by the post-test. Figure 2 indicates the percentage of students in each group that answered each question correctly.

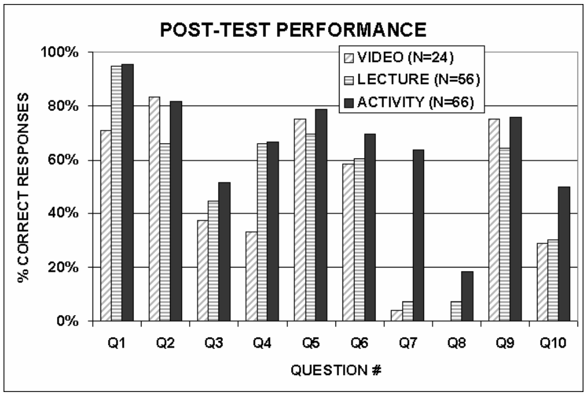

FIGURE 2. Percent of students getting each question correct on the post-test for each group.

Overall, the activity group outperformed the lecture or the video group on most of the questions. The activity group showed the highest percentage of correct responses for question 1. This question assesses the idea that when two surfaces become very smooth the friction force increases because of the increase in the number of atoms that would be electrically interacting with one another. This was one of the important target ideas of the instructional materials. Therefore, it appears that the activity was successful in helping students understand this target idea, as measured by this question.

The greatest disparity between the activity and the lecture or video groups is seen in question 7. This question asks students to choose a graph that depicts the relationship between friction and roughness in the microscopic domain. It appears that students who performed the activity and drew the graph for themselves were better able to do so than those who merely saw the instructor draw and explain the graphs.

In Fig. 2, we see that the question with the lowest percentage of students in all of the three groups answering correctly is question 8. This question asks students to choose an explanation of why it is equally easy to drag a block of wood on its wide side or its narrow side. The correct explanation is that in both cases – wide or narrow side being dragged – the microscopic area of contact is the same. Most students selected the response that states that force of friction does not depend on contact area. This statement, which is commonly found in most textbooks, is used to explain macroscopic friction. Thus, it appears that when a question demands thinking microscopically students tend to revert to commonly held ideas.

The other two low-performing questions (below 60% correct) for the activity group were questions 3 and 10. Question 3 asks students to predict what happens to the force of friction between two surfaces in a weightless environment. Clearly, students had not performed this activity, so when asked they tended to rely on the macroscopic view of friction. Question 10 asks them to select factors that affect friction at an atomic level. Almost all students who answered this question incorrectly included not just microscopic factors (area of contact and electrical interactions) but also macroscopic factors.

CONCLUSIONS

Based on our results, the developed hands-on and minds-on learning materials appear to be effective in enabling students to learn the target ideas as measured by our test. These ideas include the electrical origin of friction and how it varies with roughness in the microscopic domain. Students appear to have difficulty, however, with other ideas pertaining to the role of contact area and the factors affecting friction in the microscopic or macroscopic domains.

The hands-on and minds-on learning materials also appear to be superior to direct instruction either by lecture or videotaped lecture. This latter result aligns with evidence of the superiority of interactive engagement over traditional methods as cited elsewhere [6].

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