B. Experimental control of variables reasoning

This activity started with each student designing an experiment to determine what effect mass and surface area have on static friction. Then students were brought together for a pendulum demonstration. Students were asked to come up with possible variables that would affect the period. The students identified mass, length, angle of release, and shape of the object as possible variables. Students were presented with two comparison pendulums and asked what conclusions, if any, they could make from those two pendulums. After class discussion, the periods of the two pendulums were demonstrated and conclusions discussed. Several different demonstrations were done in this manner with the students offering suggestions before each demonstration on how to change the experiment to account for specific variables. The demonstrations covered multiple options including: a variable has no effect, a variable does have an effect, uncontrolled experimental set ups (e.g. varying mass and length), and unchanged variables (e.g. varying length but asking about mass).

Next, students combined their friction experimental designs, made changes if needed, and carried out their experiments with force probes and/or track tilt. Finally, they graphed their data and presented their findings to the class.

C. Results of the instructional modification

The overall finding is that both modifications improved the skills tested and did so in approximately equal amounts for each instructional activity. This data is presented in Table II.

For single-trend graphs and pictorial data, the greatest improvement was in students' ability to correctly identify uncontrolled experiments and to understand that these experiments will not convey information about the relationships among the variables (an 11% gain). Students improved the least on controlled experiment and changed variable questions (a 6% gain), but this was still statistically significant ($F = 4.1$, $p < 0.001$, effect size of 0.29). The two instructional activities were not significantly different from each other in overall improvements.

On the friction and light bulbs quizzes, students performed significantly better than they did without the instructional activities. ($F = 5.1$, $p < 0.001$, effect size of 1.1 for friction and $F = 7.4$, $p < 0.001$, effect size of 1.6 for bulbs.) The two instructional activities are not significantly different from each other for either the friction or light bulbs quizzes. (There was a difference between the means of 0.7% on the friction quiz and 2.4% on light bulbs quiz with the experiment instruction being slightly larger on both.) What is especially notable is that students are scoring the same on the light bulbs quiz and the friction quiz despite the fact that they are more familiar with friction and despite direct use of friction in the lab-based modification. This suggests that students were abstracting the skills the activities addressed and not simply learning the physics of the specific scenarios.

In addition, the fact that students are only 60% correct immediately after the hour long intervention indicates the misunderstandings students have on this topic are resistant to change and may not be easily reformed.

TABLE II. Average correct response percentages after modified instruction. Parenthesis show gains over pretest/previous results.

Type	Variable X	Graphs/Pics	Friction	Bulbs
Controlled	Changed	91% (6%)	89% (23%)	91% (39%)
Controlled	Unchanged	50%(8%)	60% (18%)	61% (13%)
Uncontrolled	Changed	64%(11%)	55% (0%)	53% (21%)
Uncontrolled	Unchanged	–NA–	65% (19%)	67% (32%)

IV. CONCLUSION

Here several different experiments are described which show that many students in this algebra-based class have difficulty working with data to determine the relationships among different variables. Specifically, students struggle with questions which address a variable that was not changed (controlled in order to look at other variables), with the importance of consciously constraining their observations of the data, and with the implications of data that is not controlled. A majority of the errors are consistent with failure to control variables and illogical reasoning. Also presented are two different one-hour group activities to improve student skills - one focused on control of variables and the other focused on logical reasoning and data manipulation. Since both activities improve student understanding and skills on these types of unchanged variables and uncontrolled experiment questions, this is additional evidence that both logical reasoning and control of variables play important roles in these questions of graphical and pictorial data interpretation.

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