CHAPTER 6

THE DEVELOPMENT OF HIGH SCHOOL CURRICULUM TO FURTHER STUDENTS' UNDERSTANDING OF FRICTION AND LUBRICATION IN REAL-WORLD APPLICATIONS.

6.1 ABSTRACT.

A curriculum project was developed and enacted for 10-12th grade high school physics classes to help reinforce students' understanding of the basic concept of friction and to strengthen their ability to draw connections between their classroom studies and the practical applications of their physics knowledge in their daily lives. A series of in-class discussions, demonstrations, structured laboratory experiments, and inquiry-based learning was conducted over a three-day period. Basic sliding friction experiments conducted by the students, in conjunction with discussions of common friction examples and concerns, were used to help the students bridge to the elevated concept of lubrication. Lubrication inquiry experiments in which students measured the coefficient of friction for materials of their choosing enabled them to draw conclusions about optimal characteristics for good lubricant systems. An evaluation of the curriculum based on survey questions conducted both before and after the project indicated that students felt their ability to recognize practical applications of science had been improved by the project.

6.2. BACKGROUND.

Friction is a basic physics concept that exists in a wide range of real-world examples – car tires, ice skates, miniature gears, boating, swimming, plane flight, and many more. However, while all high school students are introduced to friction in physics classes, many do not associate the classroom information with the applications in their common lives.[1,2] If they are unable to observe the connections between their study of friction and the concepts in practice, their understanding of slightly elevated ideas like lubrication will also be weaker.

Many students view physics as a series of equations and symbols with little connection to reality despite the many practical examples that exist and should dissuade them of this line of thought.[3] The gap between students' learning and recognition makes it difficult to grasp elevated concepts. These problems can develop at any level of their physics education; if students can distinguish connections between their classroom study and reality earlier with simple concepts, it may help them to make connections as they progress onward to new information.

In response to these concerns in high school physics education, we have attempted to develop a curriculum project to further high school students' understanding of the concept of friction and help them make intellectual leaps from friction to the concept and practical use of lubrication. A series of in-class discussions, demonstrations, and laboratory experiments involving some inquiry-based learning were conducted with two different physics classes at Waterloo High School in Waterloo, NY, of approximately 30 total 10-12th grade high school students. This work was conducted in accordance with National Science Foundation GK-12 curriculum development to further scientific understanding. Herein we discuss how the project was successful in helping students make connections between their studies and surroundings.

6.3. PROJECT STRUCTURE.

The curriculum project was conducted over three days (with the daily class period lasting 74 minutes) immediately following the classroom studies and homework introducing the students to the concept of friction. The first two days were centered around both open-class discussions and structured laboratory experiments. The goal of these discussions was to reinforce the students' background understanding of friction and lubrication. Sliding friction laboratory experiments conducted on the first two days were used to reinforce students' knowledge of the relationship between friction, load, and contact area. The third day provided an opportunity for inquiry-based learning involving lubrication and friction laboratory studies. Dividing each class period between some experimentation and some class discussion helped to reinforce the students' experiences and knowledge and better refine the students' comprehension of the central concepts.

6.3.1. First Day

6.3.1.1. *Class Discussion*

The first day started with an open-class discussion about friction and its role in real-world applications. Students were asked to provide examples of friction at work in solid, liquid and gaseous systems to make sure they understood friction existed beyond the simplistic examples previously seen in their homework and class examples. Most students were familiar with friction between two solid objects – either between two blocks or between tires and a road – but had not considered friction in other forms.

The students were shown and allowed to handle examples of other types of solid-solid friction, including small mechanical gears and medical syringe casings. Providing visual examples immediately helped facilitate further discussion of other examples of friction. When asked to describe friction in liquids, several pointed out a boat moving through water and drag on the hull of the boat, while others described the swimsuits worn by Olympians to reduce drag on the swimmers' bodies. When discussing friction in gases, students recognized air resistance on planes and other flying crafts as an obvious example.

Students were then asked to think about what the sources of friction are and how they are represented in the examples we had discussed. This led to students easily recognizing the pressure exerted between two solid surfaces, which was followed by a more in-depth discussion of eddies developing in fluid flow both as a cause and effect of friction. We then explained how friction represented itself as forms of energy, such as the transition from kinetic to heat in solids, or from kinetic into tension in rubbery materials.

To reinforce the examples discussed in class, a demonstration of drag reduction in fluid flow was then conducted. In this demonstration, water was poured into a beaker and allowed to flow down a vertical pipe and out a horizontal pipe, as depicted in Figure 6.1. The distance that the water spouted out of the horizontal pipe was measured and marked. Water with a very low concentration of polyethylene glycol was then poured into the beaker. As the water at the outlet changed from pure water to a dilute polymer solution, the flow rate visibly grew, increasing the distance of the water spout by several inches. The class was informed that the dilute polymer solution was a demonstration of a phenomenon known as 'drag reducing polymers', where a dilute polymer concentration can reduce the friction in the fluid by up to 80 percent. Students were then asked to suggest practical applications of this type of lubrication. Having already discussed various friction examples, the students were much faster at coming up with more applications, including naval vessel travel and firefighting equipment, both of which have been studied in regard to this phenomenon.

The demo provided a starting point for a brief discussion of lubrication. It was explained that lubrication could encompass all means of reducing friction in solid, liquid, or gaseous systems. The class discussed how friction could be beneficial, such

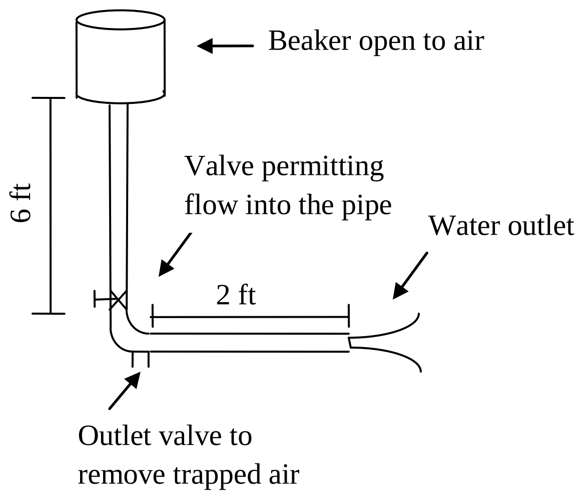

Figure 6.1. Set-up for in-class demonstration of drag reduction in fluid flow.

as reducing contact area or the material needed for applications like tires, and how friction can be detrimental, such as kinetic energy converted and lost. Having seen in fluid flow how friction could be reduced, students were then asked to think of at least two methods to reduce friction. Most were able to list changing the materials being used or adding a layer of lubrication.

6.3.1.2. *Laboratory*

Having summarized friction and practical applications of the concept, students then began working on the first part of a sliding friction laboratory experiment as depicted in Figure 6.2. The focus of the experiment was to investigate friction on a non-inclined surface without a lubricant. Wood blocks with a hook on one end were attached to a string, which ran over a pulley and was tied to a weight stand. Students could add small weights that would increase the horizontal driving force on the block when the stand was pulled vertically by gravity. The block would then be steadily pulled on a nearly frictionless surface after enough weight had been added to overcome the static coefficient of friction (COF). This nearly frictionless surface was a smooth hard plastic sheet with minimal surface roughness.

Students were asked to measure the weight required to move the block, three times each for a series of laboratory designs:

- The wooden block with a piece of sandpaper on one side

- The block covered by a sheet of plain paper (reducing roughness from the wood surface)

- The block, covered by plain paper, turned on to its thinner side

- The block, covered by plain paper, with a weight placed on top of the block

These experiments demonstrated to the students the effects of changing the surface of the sliding object, of changing the contact area, and of changing the applied normal

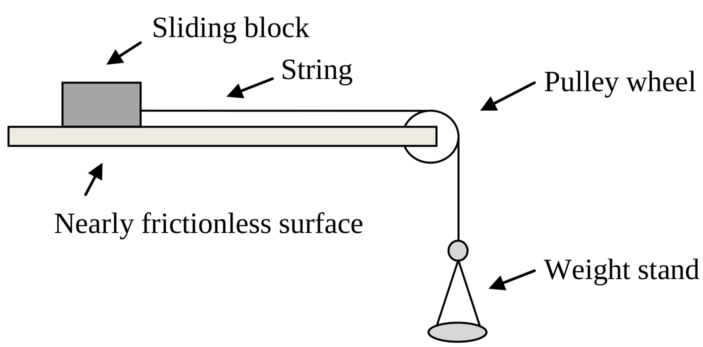

Figure 6.2. Equipment design for the sliding friction laboratory experiment.

force. From their weight stand measurements, students were then asked to calculate the average COF for each set of measurements and compare between data sets.

6.3.2. Second Day

6.3.2.1. *Laboratory*

The second day of the project began by having students conduct friction lab experiments similar to the lab they had conducted on the previous day. The main difference involved adding a slope to the platform. This served to not only reinforce the students' ability to calculate normal load for a surface at an angle, but also to help the students determine if a relationship exists between COF and angle of the platform.

Students added an angle to their platform by placing textbooks underneath the side of the frictionless surface closest to the pulley, thus creating an upward slope. Students continued working in their same groups of three as the previous day, and were asked to make three weight measurements and COF calculations for each of three angles.

6.3.2.2. *In-Class Discussion*

After students had finished the laboratory and calculations, the class was brought together and asked to analyze which changes to their equipment design had an effect. After the groups summarized what they had measured, they were asked how the COF of the experiment could be either increased or reduced. This began to shift the focus of the experimentation and class discussions to an elevated level conceptually, hoping to push the students to begin to make intellectual leaps from a reinforced base understanding. In response to the questions, most students were able to list both changing the surface of the sliding block and adding a lubricant.

A demonstration involving equipment borrowed from Cornell University was then conducted to reinforce these methods of changing the COF. Five different strips of material (glossy paper, plain paper, polyester, teflon, and nylon) were taped lengthwise to a clipboard. When a motor was turned on, one end of the clipboard would slowly lift to create a gradually-increasing slope. Small discs placed on each strip would then slide down the slope after the slope was steep enough to allow the disc to overcome the static COF. Students were shown the process using both rubber stoppers and metal discs.

This demonstration served to simplify the basic methods of lubrication. Having observed five different substrate materials and two different sliding objects, the experiment indicated how the static COF changed not only between different surface materials but also for different sliding materials. It was explained that the introduction of a lubricant was similar to changing the substrate, and the friction properties would change when different materials were used. The different sliding materials represented the interaction between the opposing surfaces, and that lubricants could be ineffective depending on how they interacted with the sliding surface.

Building on the lubrication discussion, students were told they would be able to investigate several friction-changing lubricants in an inquiry-based atmosphere the next day. Each group was informed they would investigate three different lubricants and were asked to bring in household materials they chose to study. Examples we suggested included liquid-like materials such as ketchup and toothpaste, and more solid chemicals such as deodorant and baking powder. Finishing the in-class discussion, each group planned the experimental design for their inquiry study, and predicted the results they would observe for each lubricant.

6.3.3. Third Day

6.3.3.1. *Laboratory*

Almost the entire third day of class involved the students completing the inquiry-based portion of the laboratory. Most groups volunteered to bring in their own materials instead of using some basic substances provided. The lubricants brought in by students included bathroom soaps, cocoa powder, pudding, BB gun pellets, fruit candy, and eggs.

Three different types of sliding discs had been manufactured in a Cornell University machine shop to provide discs that would be easy to wash and not interact with the lubricant. There discs were approximately three inches in diameter and 1.5 inches thick. Most plastic discs used in the laboratory were delrin. To allow for groups to measure the effect of interaction between the lubricant and the sliding object, one teflon disc and polycarbonate disc were also manufactured and provided.

Students were first asked to measure the COF of the disc with no lubricant provided to provide a control for their experimentation. After that, they were expected to test the sliding friction of three different lubricant systems and take a minimum of three measurements to determine each COF. The students were offered some guidance at times, but otherwise were left to conduct the experiments on their own.

The lubricants that the groups chose not only provided an incredibly wide range of COFs, but also introduced students to other types of friction beyond the standard static friction they were familiar with. One group wrapped their disc in fruit roll-up candy and let it slide on a pudding coated-track; the pudding dissolved the candy to generate an extremely low COF, demonstrating the potential of reaction-aided lubrication. A group investigating BB pellets observed rolling friction with their experiment. Several groups attempting to measure powdered lubricants witnessed low initial COFs before the discs stopped as a result of a build-up of the powder. This repeated development introduced the concept of plowing friction.

6.3.3.2. *In-Class Discussion*

An in-class discussion followed the laboratory to summarize the friction experimentation and help the students draw conclusions from their lubrication studies. After discussing the COFs measured and evaluating their successes, students recognized that adding a material would not necessarily decrease the friction but could potentially increase the COF. From the wide range of lubricants used, the students came to agree one important criterion to control was the lubricant viscosity. A high solid-like viscosity could increase friction and prevent sliding from occurring, while a liquid-like mobile fluid could cause spread too easily. They thus determined that a balance needed to be achieved between a lubricant that would remain in place on the substrate and a material that would allow for a non-sticky, more liquid-like surface. The discussion concluded by asking the students which systems would be most viable in real-life applications.

6.4. EVALUATION OF THE CURRICULUM.

In order to evaluate the success of the curriculum, the students were asked to fill out a series of survey questions pre- and post-curriculum. Five short answer questions were asked both before and after the project:

1) How would you define friction?

2) What causes friction?

3) What can you do to reduce friction?

4) What are some of the disadvantages of having a system with high friction?

5) What are some of the advantages of having a system with high friction?

Because the curriculum was conducted after the concept of friction had been introduced in terms of its basic physical nature and related equations, the initial answers for these questions reflected the students' experience having previously studied the subject matter. Few students changed their answers for any of the questions between surveys. The only question that demonstrated any change in the students' knowledge was question 3; approximately one-fifth of the students surveyed changed their pre-project answer from "smoother surfaces" or "reduce rough surfaces" to an answer reflecting the benefit of changing both the surface and adding a lubricant layer.

Two rating statements were presented in both the pre- and post- project surveys, asking students to choose the answer that described them best. Ratings ranged from 1 to 4, with 1 meaning strong disagreement, 2 meaning disagreement, 3 meaning agreement, and 4 meaning strong agreement. These questions are reported in Table 6.1.

A t-test was conducted on each set of answers. While the answers from all the students reflected a positive understanding of friction as well as personal enjoyment in science classes, overall no statistically significant change between the pre- and post-survey questions existed.

Six rating statements were presented in the post-project surveys, also based on the 1 to 4 scale. With an average value of 2.5 reflecting no opinion, the standard deviation of these results was used to evaluate the significance of any of the students' responses. The questions and results are reported in Table 6.2.

Several conclusions can be drawn from these answers. As was seen from the questions in Table 6.1, students' opinions about science classes did not change because of the project. However, students felt that the project was successful in its primary goal of helping them develop the ability to draw connections between their

Table 6.1. Survey questions based on a 1-4 agreement scale, asked both pre- and post-curriculum.

Question	Pre-Mean	Post-Mean	P-value
I understand the general process and concept of friction.	3.17	3.26	0.624
I enjoy science.	2.87	2.74	0.641

Table 6.2. Post-curriculum survey questions based on a 1-4 agreement scale.

Question	Average	St Dev	Meaning	Significant?
After conducting this research experiment, I feel I understand how science can be applied to real-world applications.	**3.28**	**0.69**	**YES**	**YES**
I am more exicted about science than before	**1.89**	**0.88**	**NO**	**NO**
I enjoyed this research experiment more than most labs.	**2.91**	**0.73**	**YES**	**NO**
After conducting this research experiment, I feel I understand how scientists design their own experiments.	**2.74**	**0.86**	**YES**	**NO**
Doing this experiment, I was more bored than in most classes.	**1.57**	**0.66**	**NO**	**YES**
This experiment was more difficult than most labs.	**1.65**	**0.71**	**NO**	**YES**

studies and the applications of those studies in their daily lives. Students' strong agreement with feeling more knowledgeable about practical science after having completed the project indicates the curriculum helped to strengthen their students' understanding of friction.

A common difficulty with inquiry-based laboratories is that concrete answers do not exist, thus denying students a definite goal that they can work toward.[4] Students conducting these type of experiments will often be frustrated, as it represents a dramatic change from highly structured study to more open-ended questioning. This typical frustration was indeed characteristic of these students, as reflected by the lack of significant positive answers from the third and fourth questions. One solution for this issue would be to introduce other inquiry-based laboratories for other physics experiments to help students feel more comfortable with this advanced scientific technique. A positive can be taken in that students did not find inquiry experiments to be difficult, as evidenced by the final question.

Four short-answer questions were also asked as part of the post-project survey. The number of students with a certain answer was grouped together as listed in Table 6.3. The short answers indicate the students viewed the curriculum as an entire three-day project and did not differentiate between the in-class discussions and the laboratory experiments. While many students did not feel the project could be improved, nearly as many students felt the project should be expanded to allow them study with more lubricant materials. This is a reflection of the students' enjoyment of the inquiry-based experimentation, even though they were uncomfortable with the open-ended nature of the study. Significant enthusiasm was shown for the lubrication inquiry experiments, not only for the hands-on nature of the experimentation, but also the freedom each group had in being able to choose their own lubricants. It is also important to note several students listed enjoying being able to conduct their own

Table 6.3. Post-project short answer responses, with the number of responses of similar answers.

1) What did you especially like about the in-class portion of the project?	
Working with and suggesting their own materials	7
Hands-on nature of the experiment	4
Freedom in experiment design	4
Having a laboratory	2
Being able to investigate material already studied	2
Other	2
2) What did you especially like about this experiment?	
Working with different lubricants	9
Having freedom and control over the experiment	5
Witness friction and lubrication effects	4
It was fun	2
Hands on nature of experiment	1
Other	1
3) What would you suggest for improving the in-class portion of the project?	
Nothing	7
More time	3
Expand the inquiry-based experiment	1
Expand the in-class discussion	1
(Suggestions for equipment changes)	2
Other	4
4) What would you suggest for improving the lab?	
Nothing	6
Fewer calculations	5
More time to work with more materials	4
Less independence between groups	2
Other	3

investigation of real-world friction and lubrication examples after discussing many applications in the beginning of the project.

6.5. CONCLUSIONS.

We have developed a curriculum to help students draw connections between their studies in physics classes and the many real-world applications that exist in their daily lives. Focusing on the basic physics concept of friction and then slightly elevated, related concept of lubrication, students were provided with a series of structured friction experiments and demonstrations to help summarize their knowledge of the subject matter. Students then progressed into an inquiry-based study of the lubrication properties of common household materials.

Survey questions showed that while the students did not feel their knowledge of friction improved, they strongly believed their ability to connect their studies to common examples and uses was strengthened. The students did not necessarily feel comfortable being able to design their own experiments, but greatly enjoyed having freedom in their ability to experiment with a hands-on activity.

A number of changes could be made to the structure of laboratories or in-class discussions to accommodate other teachers, their classrooms and their students. The demonstrations could be modified or eliminated based on the materials available or the extent of the in-class discussions. Introducing other inquiry-based laboratories into the overall curriculum would also help students adjust to designing their own experiments and feel more comfortable with studies where the final goal is open-ended. The nature of the project serves to reinforce much of the classroom information already taught to the students. It is possible that by presenting the material earlier in the range of class friction studies, the students' understanding of the subject matter would be accelerated.

REFERENCES

(1) Halloun, I. *J. Research in Science Teaching* **1996**, *33*, 1019-1041.

(2) Duch, B.J. *AIP Conf. Proc.* **1997**, *399*, 557-566.

(3) Elby, A. *American J. Physics* **2001**, *69,* S54-S64.

(4) Colburn, A. *Science Scope* **2000**, *March*, 42-44.