THE BICYCLE: A VEHICLE FOR TEACHING PHYSICS

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"The beauty of the bicycle resides in its sincerity. It conceals nothing. All its workings are open and visible." J. Bertaut (1936). And, these workings can be used to teach a wide range of physics concepts. During the past several years, a group of physics educators from six countries have collaborated on two aspects of physics education using the bicycle. The result was a set of interactive lessons centered on the scientific and cultural aspects of the bicycle. Recently, I have expanded on these materials in two ways. First, I have investigated the early 20th Century history of bicycle design as an example of how societal and technological issues interact. Second, I have begun exploring the use of portable computer data collection systems to add a sophisticated component to the teaching materials.

1 Introduction

Developing instructional materials relating to the bicycle has involved international cooperation over a long period of time. In this paper I will discuss this cooperative effort and how it can be extended to India.

Much of this work is now centered at the Physics Education Research Group at Kansas State University. This group has a rather large research and development effort. We have about 10 students. Most of them receive degrees in physics but a few obtain their PhD in science education.

2 Cultural Differences in the Interpretation of Bicycle Technology

I began looking into the physics of the bicycle for two reasons. One is very selfish; I like bicycling. The other one is that the bicycle provides a way in which you can talk about science, technology and how it interacts with local culture. Different cultures use the bicycle in many different ways. The uses range from a “beast” of burden to recreation to a beer keg carrying bicycle at the Amsterdam airport. These situations are quite different although the science and technology is quite similar. In India we can see many different types of bicycles and uses in almost any location. The pictures in Figure 1 show very different situations and types of bicycle.

One bicycle that seems unique (in my experience) to India is the one in Figure 1b. The pedals are operated by the hands instead of the feet. Because of the very long and big chains, it does not look very efficient. Obviously, this bike would be good for people who have difficulties with their legs, but here it seems to be used by a lot of other people as well. I need to investigate it further.

A Google search on “India and bicycles” led me to discover a sport that I had never heard of – bicycle polo. India is a major player in this sport. Of the seven world cups in

Figure 1. Three different bicycles each of which are being used for different purposes and were seen in Delhi.

bicycle polo, India has won four of them. The US, Canada and Australia have won the other three.

3 Some Impacts of the Bicycle on Society

Bicycling has been part of our culture for almost 200 years and has an important impact. For example, Susan B. Anthony was a pioneer in women's rights in the United States. In 1896 she stated, "[Bicycling] has done more for the emancipation of women than anything else in the world." Ms Anthony continues to explain why the bicycle was so important to the 19^{th} and early 20^{th} Century women's movement. In the late part of the 19^{th} century, particularly in the United States and England, bicycling became something that involved a large number of women. It provided them with a new level of independence because they did not have to wait for a man to bring his horse and carriage in order to go from one place to another. Thus, it changed the mobility of women forever.

In my Google search I found an item related to India – particularly in small villages – related to bicycles and women. In some villages women are using bicycles to carry water. The bicycle changes the nature of their lives quite a bit. So, we can combine these ideas that are related to social and cultural issues with the scientific side to make physics attractive to a broader audience, particularly girls and young women as discussed in other papers in this volume.

Bicycles are a scientific and technological object which can be used for recreation and sport and can also have an impact on society in important areas of transport. In using the bicycle as a context for teaching science an important idea is, "The beauty of the bicycle resides in its sincerity. It conceals nothing. All its workings are open and visible." This statement, first made by J. Bertaut in 1936, is an important reason for studying the bicycle. You can easily see how it works and figure out what is going on.

4 Bicycles and Physics Teaching

The bicycle has been used for teaching physics and engineering for a long time. For example, Frank Witt, a mechanical engineer at MIT, put together a laboratory course in mechanical engineering which involves the bicycle and is really just applied physics.[1] In the 1970s a module in *Physics of Technology* addressed basic physics of the bicycle.[2] These materials were originally a project of the American Institute of Physics and now the American Association of Physics Teachers owns the materials.

My international collaborations on the bicycle began in The Netherlands in the early 1980s. Robert Fuller and I had completed an interactive videodisc[3] the helped students trace energy flow through a bicycle. Simultaneously, the staff of the PLON project in The Netherlands was creating modules on the science of traffic. These teaching units later became *Motion I* and *Motion II*.[4] In The Netherlands as in Delhi a large fraction of the traffic is bicycles. So, the *Traffic* unit included a large amount of the physics of bicycles. Since then we have been collaborating with physicists in The Netherlands on using the bicycle to teach physics.

The Open University in Great Britain also used bicycles in various courses. Most of these courses are now defunct, but their faculty have some nice materials available, including a film on which they worked with the BBC on the history of the bicycle.[5]

The most definitive text on the bicycle is *Bicycling Science* by David Gordon Wilson,[6] a retired mechanical engineer at MIT. The third edition has been published recently. It has almost all of the information one could want to use in teaching the physics of the bicycle.

5 International Bicycle Project

About 10-12 years ago we decided to try to become more formal with our interactions between particularly the US and The Netherlands but we also included several other places in Europe. (Our reason for limiting the project to Europe was financial; the US Department of Education and European Community had a grant program that could support our collaboration.) Thus, we began an international bicycle project. The project was called "Science, Culture and Technology of the Bicycle." The goal was to develop some ideas on how to teach basic science, how that science has an effect on culture and how a local culture could affect the technology that is based on the science.

Two approaches were involved. One was an exchange of students, so undergraduate students came from Europe to the various institutions in the US and students from the US went to Europe. They were to complete a project that was somehow related to the bicycle. It did not necessarily have to be a science project. For example, some students did research on social sciences and the bicycle. The student projects ranged from very basic laboratories for teaching science of the bicycle to comparisons of how bicycles were marketed in the different countries.

At the end of the project the faculty worked with some secondary school teachers and brought many of the ideas into a collection of lessons which are listed in Table 1. These lessons range from basic mechanics to thermodynamics. The thermodynamics lessons focus on the bicyclist. Dissipation of thermal energy is very important. For example, those of us who are bicyclists know that one of the worst situations is traveling at the same speed as the wind because there is no relative motion between the rider and the wind. Thermal energy dissipation is quite different in this situation from others. Another concept we have the students investigate is bicycle clothing. Bicyclists can buy very expensive bicycling clothes which are supposed to help the heat dissipation. One of the lessons helps students address the question, "Do they really work or is it just another way to get money?"

Table 1. Bicycle Project Lessons.

- Bicycles in the World
    - Evolution of the Bicycle
    - Fundamentals and Attributes of a Bicycle

• The Bicycle Alone
  o Getting Geared Up
  o May the Force Be With You
  o Torque Out!

• Bicycle and Rider as a System
  o Drag and Roll
  o What a Drag!

This project has a website at http://www.science.uva.nl/research/amstel/bicycle/.

6 The Next Step: Broader International Collaboration

At this time I want to encourage other physics teachers to get involved in this effort. So, the remainder of this paper will focus on future possibilities, particularly those in which teachers in the developing world can be strong contributors. We would like to collaborate on both research and development with local modifications. The model for this type of effort is similar to *Wikipedia* – a web-based encyclopedia where anyone can contribute. (See http://www.wikipedia.org/.) If you read an article in this encyclopedia and do not like it, you click a button and rewrite it. Then, your version becomes the latest one. If you stated something wrong, then supposedly someone else will notice that and fix it right away. I would like to set up a similar approach for lessons related to teaching physics in the context of the bicycle. Anyone could post lessons. If someone posts a lesson on a type of bicycle that is only available in the US, anyone else could modify that lesson to be useful in other locations. The revised versions would be available to others. In this way we can collect lessons that could be used in many different locations and have local contexts.

We could collaborate on a number of different topics. Just taking some of these old lessons and bringing them up to date or making them more local is something that would be very valuable. Involving students in looking at how the bicycle is used in different cultures and how the basic technology varies from culture to culture would be quite valuable.

As a concrete example I will return to bicycle polo. The photos at http://www.bikepolo.net/gallery/view_album.php?set_albumName=InidaUSA1 show scenes from a match involving the US and India. (India *is* misspelled in the URL for the Web page.) A very important difference between the two teams is helmets. If you look at the pictures, all of the team members seem to wear helmets except the Indians. This difference involves culture as well as safety. The safety is very deeply embedded in some very simple physics which the Indian players probably understand well. But something related to culture keeps them from using helmets.

7 Some Example Lessons from Past Projects

Teaching with the bicycle can involve many levels of instructional technology. Figure 2 from a Dutch lesson shows a way for students to investigate the friction in a bicycle using a low technology experiment. They put it up on a ramp where they can calculate the gravitational potential energy. Then they release the bike and measure how far it goes before stopping on a flat surface. By comparing the initial energy with the work done the students can determine the force of friction on that bicycle.

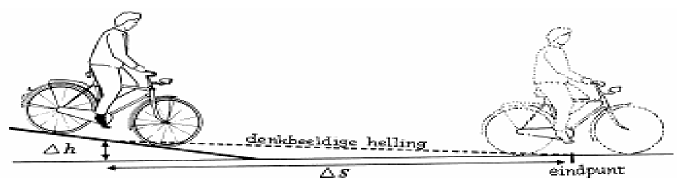
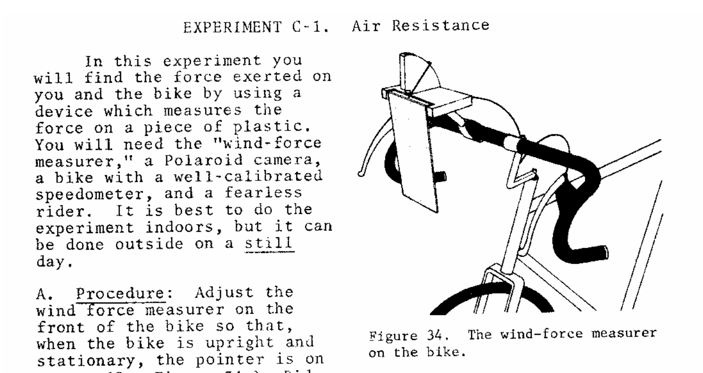


Figure 2. A low technology approach to measuring friction in a bicycle. (From Reference 4.)

A similar low tech approach is shown from a US lesson in Figure 3. Air resistance can be measured with a very simple device that just blows backwards when the bicycle is moving. By calibrating the device using gravity, the students can read the approximate force of air resistance. Many experiments with simple technology can produce some good order of magnitude calculations.



EXPERIMENT C-1. Air Resistance

In this experiment you will find the force exerted on you and the bike by using a device which measures the force on a piece of plastic. You will need the "wind-force measurer," a Polaroid camera, a bike with a well-calibrated speedometer, and a fearless rider. It is best to do the experiment indoors, but it can be done outside on a still day.

A. Procedure: Adjust the wind force measurer on the front of the bike so that, when the bike is upright and stationary, the pointer is on

Figure 34. The wind-force measurer on the bike.

Figure 3. A way to measure air resistance (From Reference 2).

A medium level of technology is presented on our videodisc, *Energy Transformations Featuring the Bicycle*. We put bicyclists in wind tunnels and measured the force with a spring scale. Then we provided diagrams of the riders so the students could numerically integrate by counting squares to determine the frontal area of the bicyclists.

A lesson developed during the international bicycle project involves the standard speedometer sending unit on a bicycle, which is just a reed switch that a magnet passes once per revolution. The output is connected to an audio recorder which records a click each time the magnet passes the switch. The resulting data are analyzed in a spreadsheet and give results such as velocity versus time for the bicycle.[7]

For higher technology we are beginning to explore portable data collection systems. One example is Pasco's GLX Explorer. This portable device is, in effect, a small computer with sensors. We can measure variables such as acceleration. A total of four sensors can be used at any one time. So far, we have had limited success with this device. An important issue is to eliminate extraneous vibrations and motions.

Another concern is how students will learn physics using the context of the bicycle. My colleague Sanjay Rebello is conducting research on how students apply physics in the context of everyday objects. One of the everyday objects is a bicycle. We would be interested to see how this research is reflected in students in other countries.

8 Conclusions

In summary, the bicycle is a ubiquitous device. Almost all cultures use it for recreation and/or transport. It is also a device that incorporates a large amount of classical physics. (With LED bicycle lights we could even get into modern physics.) The bicycle's use and even its form differ from culture to culture. Thus, it provides an excellent context for the development of teaching materials for physics and for helping students understand how physics and technology is interpreted in various cultures.

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