Video-Based Labs for Introductory Physics Courses

Analyzing and Graphing Motion on Video

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Video-based labs (VBL) are a powerful tool for improving student understanding of one of the most difficult and important topics in physics: graphs. This article describes common student graphing difficulties, the history of VBL, techniques for improving student understanding of graphs, and software for acquiring and analyzing video data.

Kinematics, the study of motion, is critical to understanding physics. For that reason it is among the first topics covered in introductory physics classes and it acts as a foundation for much of the rest of the course.

Graphs are an important element in the study of kinematics. Interpreting the large amounts of data displayed on graphs is critical to making sense of the field. Because features on kinematics graphs, such as slopes and areas, are directly linked to observable physical quantities such as distance traveled, speed, and acceleration, kinematics graphs are used as objects of study and a language of learning in physics instruction.

Unfortunately, studies indicate that students do not share the vocabulary, nor are they able to easily comprehend graphs (Beichner 1994; McDermott, Rosenquist, and van Zee 1987; van Zee and McDermott 1987). A valuable device for students facing these obstacles is a video-based lab (VBL). The link between graphing and kinematics makes video-based motion labs a particularly powerful tool for combating some of the most common difficulties students encounter when they interpret graphs.

The most frequently confronted problem when working with kinematics graphs is the belief that a graph is some form of photographic-like replication of the motion event. The "graph as picture" error might occur when a student is asked to draw a velocity or acceleration versus time graph of a bicycle rolling down a hill and over a small bump. The resulting drawing often duplicates the physical configuration of the given motion event, right down to the bump at the end of the path.

In effect, the student misinterprets the axes, creating a graph of vertical position versus horizontal position (y vs. x) rather than a graph of velocity versus time (v vs. t). Unfortunately, the "graph as picture" error can lead to a correct position versus time graph. This situation will occur whenever the horizontal motion of the object is a linear function of time, making the graph as picture error difficult to detect. Although this error is probably peculiar to kinematics, it indicates a general deficit in graphing skills, namely, students are not aware of the abstract nature of graphing as a way to represent data of a concrete situation.

Many students have trouble determining slope. One critical misinterpretation is referred to as "slope/height"

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confusion. Asked to indicate the point of maximum or minimum slope on a graph, students often pick the place with the largest or smallest ordinate value, where the slope is actually zero (Mokros and Tinker 1987; Barclay 1986). Research by one of the authors found other difficulties related to slopes, including students' surprising inability to calculate the slope of lines that do not pass through (0,0) even though they have little trouble finding the slope of lines that pass through the origin (Beichner 1994).

Several tools are available to help students understand kinematics graphs. With the rapidly increasing availability of technology in the schools, many excellent instructional packages have been developed. One of the most popular is *Graphs and Tracks*—software that takes students back and forth between a simulated ball rolling on a track and kinematics graphs that describe the ball's motion (Beichner et. al. 1995).

Ultrasonically based motion detectors with accompanying analysis software packages have been thoroughly studied and found to be highly effective in motivating students and helping them to acquire an intuitive understanding of kinematics (Brasell 1987; Redish, Saul, and Steinberg 1997; Thornton and Sokoloff 1998). More recently, software packages for analyzing motion on videos have become widely available.

The idea of using video to analyze motion is not new. Early work by Dean Zollman, Robert Fuller, and others involved the use of videodisc images displayed on a television screen (Zollman and Fuller 1994). Students placed plastic sheets on the screen and made a mark at the location of the object as it moved from frame to frame. These marks were then used to produce a graph of the object's motion. Videodiscs like Zollman's *Physics of Sports* have proven to be very useful in helping students closely examine the motion of real objects.

Computers have been used in physics labs to digitize movies and generate graphs of moving objects in the video since the mid-1980s (Beichner 1989). The relatively primitive technology available during those early efforts resulted in very grainy black and white images. Objects in these early digitized movies were difficult to recognize unless they were moving because of the lack of color or even shades of gray.

Advances in computer technology now make the capture and playback of high resolution movies quite easy. In fact, the hardware and software have advanced to the point where students can concentrate on the physics depicted in the videos and not on the techniques required to collect the data (Beneson and Bauer 1993; Graney and DiNoto 1995; Molnar 1995).

The main control panel for a piece of software that automates the capture process is shown in **figure 1.** Students attach a computer-controllable VCR or videodisc player to the video input of their computer. They then specify how many frames will be "grabbed" and how many frames of the original video source are to be skipped between captures.

The on-screen video controller is used to advance to the beginning of the desired sequence before clicking the record button. The video source is automatically advanced through the frames while the video capture program directs the computer to capture images, compress them, and then store them on disk. Operation is the same whether students are collecting images from a videodisc player or from a computer-controlled VCR—the lower slider on the controller switches back and forth between the two video sources.

Figure 1. The control panel from a software package that lets students collect video from a videodisc player or VCR.

Once the movie is saved to disk, it can be analyzed. About half a dozen different software packages are now available to do this (Gastineau 1995). The particular tool described here was created for use in introductory physics laboratories at the high school and college level. It allows students to videotape motion events and use the graphing capabilities of a microcomputer to carefully examine and analyze the motion. More specifically, the computer replays the video on its screen while simultaneously creating a graph of position or speed as a function of time.

Students can also "draw" motion events using either painting programs or a programming language. So, besides its obvious use as a data-gathering and analysis tool, video-based lab software can be used by students to analyze previously recorded motion events or even simulated microworlds where the laws of motion are programmed into the system by either the students or their teacher.

We contend that by seeing both the concrete motion event and the abstract graphical representation of that motion, students will be better able to make the cognitive links between the two and may confront some of their graphing misconceptions (see **Figure 2**). As the student steps through the video, the position of the object in the video and the corresponding point on the graph are both highlighted. Tools for measuring slope and area from the graph and distances and angles on the video can also be used to make critical connections (see **Figure 3**).

Our research found instructional benefits for students at three different high schools and a four-year college, suggesting that the VBL technique can be useful in a variety of educational settings (Beichner 1996). We were particularly pleased when our studies showed that females benefited as much as males from the software.

Video-based lab analysis can also be used to develop models for mechanical phenomena. **Figure 4** shows results from using coffee filters to study the effect of wind resistance on falling objects. Because the filters can be stacked, the weight can be increased without changing the cross-sectional area. When the filters are dropped, the stack speeds up until the drag force equals the weight. After the terminal velocities of stacks with different weights are measured, the data are entered into a spreadsheet and analyzed.

The relationship between drag force and velocity in this situation results in a graph of velocity squared versus the drag force, fitting a straight line through the origin. Data from a mi-

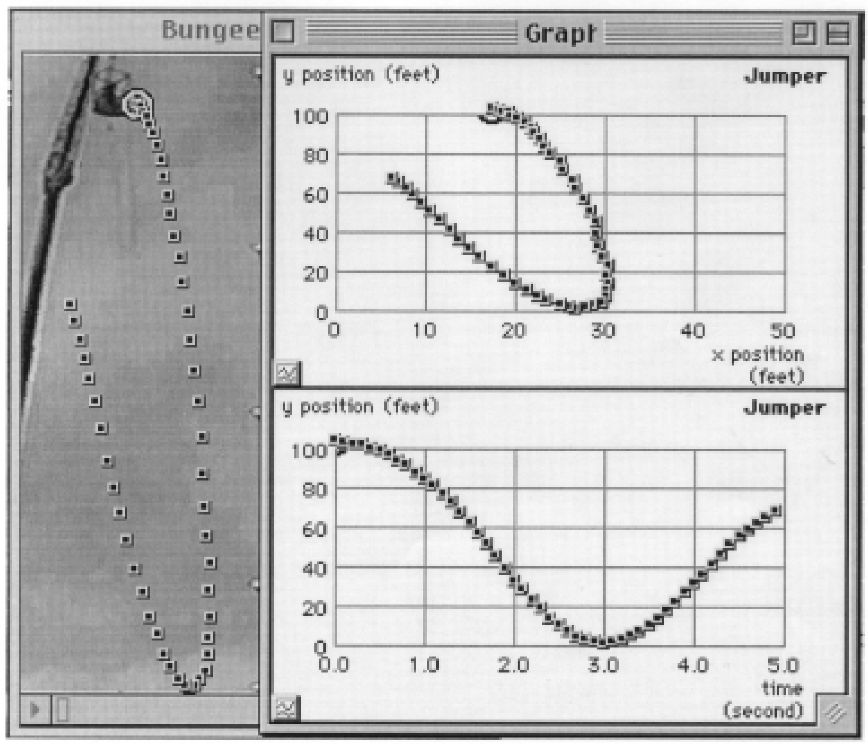

Figure 2. A screen from a video motion analysis program showing how the "graph as picture" misunderstanding can be confronted. Students compare the graph of *y* vs. *x* (which mimics the actual motion) with a kinematics graph of *y* vs. *t*.

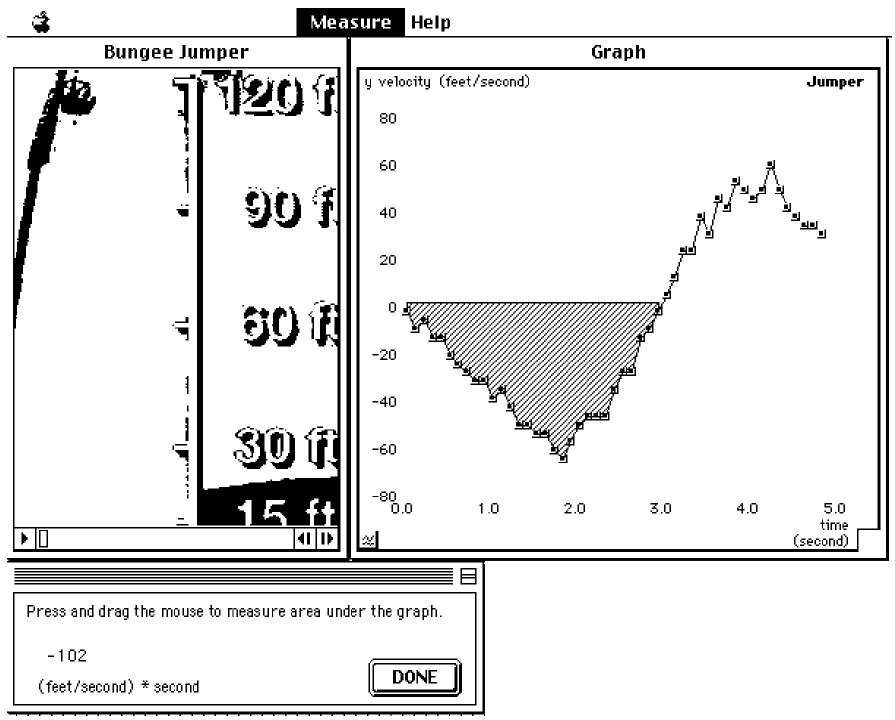

Figure 3. This combination of dialogs and windows from a video motion analysis program shows how students can measure distances directly off the video and compare those data to the area under a velocity vs. time graph.

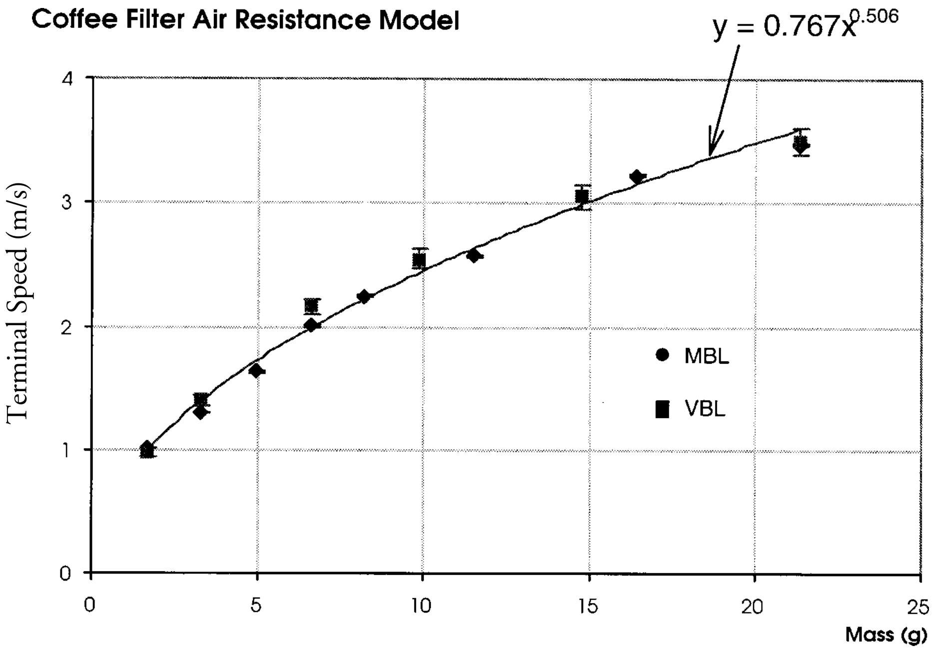

Figure 4. Graph from a spreadsheet analysis of VBL and MBL data for falling coffee filters. Squaring both axes gives a straight line indicating that the air drag force is proportional to V^2.

crocomputer-based (MBL) ultrasonic position sensor are placed on the same graph for comparison to the VBL results.

The flexibility in applying VBL pedagogies is the key to improving student motivation. As they use the same tool in a variety of situations, students become very familiar with its operation and evolve into "technology experts."

This has already been assessed in our earlier research where we found that fully 80 percent of the students involved in the study would rather use VBL than any other kinematics data collection technique (Beichner 1990).

A major contributor to acceptance of this instructional method is that students are able to use the same data collection and analysis techniques for real-world situations as they do in school lab studies. We believe that to get students excited about science, it is vitally important to help them see the science in their everyday world. VBL can be specifically geared toward bridging the gap between "artificial" laboratory experiments and the collection of data from the students' day-to-day experiences.

It is important to realize that the purpose of VBL activities is not to eliminate labs or replace them with simulations. VBL provides students with a tool that can help in the study of prerecorded real-world or artificially produced events. Students can analyze lab and real-world phenomena, either as homework or in class. VBL can also supplement other hands-on experiences like MBL sonic ranger lab exercises, give students an opportunity to "play back" the motion to make sure they understand the critical aspects, and help focus their attention on those aspects of motion where known motion and graphing misconceptions exist.

The versatile VBL approach is yet another tool that teachers can utilize to help their students learn the fundamental scientific skill of interpreting graphs and grasp one of the most difficult and important topics in physics. ❑

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