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MODELLING THE MOTION OF AN ATHLETE: AN INTERACTIVE VIDEO LESSON FOR TEACHING PHYSICS*

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ABSTRACT

By using interactive video, particularly the videodisc, students can view and analyze situations which happen outside the classroom. The videodisc enables students to observe and measure the motion of athletes. To analyze the data from such motion the students can develop models of the athlete; then, compare the predictions of the model to the actual motion. Using this procedure students learn about motion and, more importantly, begin to understand the use of models in scientific work.

Physics teachers have long used visual media to show how the principles of physics can be applied to everyday events. These examples seem to motivate students and to improve their understanding of the concepts being taught. Most of these presentations have been qualitative in their approach to the physics. The difficulty in working with media such as films and slides limited the amount of quantitative information which could be acquired from them. While some notable

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exceptions to the qualitative presentation exist [1], few quantitative visual presentations have been used in instructional settings, particularly in the laboratory.

The availability of the interactive videodisc has created a vastly different situation with respect to the student use of visual media. Because the videodisc is quite easy to use, instructors allow students to use it in settings which would have been quite difficult with other visual media. Students may search to any frame (picture) on the videodisc by pressing a few commands on a keypad. They may then view motion at any slow motion rate from one frame at a time up to normal speed (thirty frames per second). Measurements are also quite easy. Unlike videotape, the searches occur quite rapidly, and the amount of time during which one frame may be displayed is essentially unlimited.

Because each video frame is separated by one-thirtieth of a second, a timing mechanism is built into the disc. Because each frame is individually numbered and that number can be presented on the screen, time in seconds can be determined by simple subtraction and division. Distance measurement can be made with a ruler placed on the screen as long as some known distance is available for scaling. The net result is that the videodisc provides a means by which students may complete laboratory measurements on events which cannot happen in the classroom.

Several videodiscs have been produced to exploit the data acquisition capabilities of the system [2-6]. All of these discs use video material from events which cannot be duplicated in the instructional laboratory and require that students complete measurements from the video scenes then use these measurements to analyze motion in terms of the principles of physics. Details on the development and use of these videodiscs are available [7-11].

Hardware systems for the use of interactive video lessons can vary from a stand-alone player to a sophisticated computer which controls the video output of the system and overlays computer graphics on the video images [12]. The material which has been developed for physics instruction tends to involve computer control of the video but not sophisticated overlay of the graphics and video. Primarily in reaction to the cost of sophisticated systems physics teachers who have developed software have used hardware systems which include small microcomputers, video players, and two screens—one for videodisc output and the other for computer output. The lessons for these systems have generally been developed for introductory classes and range from small sections of a lesson to rather complete packages for laboratory instruction [9-13].

While measurement has been emphasized in most interactive video lessons in physics, another important tool of the scientist—modelling—has not. Because the use of the models to describe and explain complex situations is extremely valuable to the physicist, but seldom understood by the introductory physics student, we have undertaken a project to develop interactive video lessons which will enable students to develop some techniques in using models and to understand better the value of this practice. To present these ideas and, at the same time, motivate students to want to learn physics better, we chose a popular set of motions—those involved in certain athletic events.

THE PHYSICS AND SPORTS VIDEODISC

The general purpose of the "Physics and Sports" videodisc is to present video scenes which show athletes performing events in such a way that students can take measurements from the screen. As discussed above these measurements are distance and time. Once the students have recorded these values and been given the masses of the athletes, they can calculate a wide variety of physical quantities such as velocity, acceleration, energy, and force.

Unfortunately, normal video scenes, such as those which appear on Monday Night Football, are not conducive to measurement. On broadcast television the camera moves frequently. This motion creates a very difficult situation for recording data. Thus, we decided to record most of the events for the video by using staged practices which were recorded with a fixed camera.

The physics topics and the sports video which demonstrate them on the videodisc are shown in Table 1. In selecting the video for the lessons we considered several aspects. Most importantly we wished to use events with which a large segment of the high school population could identify. We recorded events in which many people participate and deemphasized those sports in which very few people participate or which are identified as the "territory" of boys. Thus, the disc will have scenes of hitting a slow-pitch softball rather than a baseball and a few scenes from sports such as football. (Perhaps the biggest exception to this rule is competition ax throwing. Here we had a rare opportunity to record

Table 1. Physics Topics and Sports on the Videodisc

- Velocity and Acceleration
  - Start of a dash
  - Sprinter vs. long distance runner
- Projectiles
  - Shot Put
  - Long Jump
  - Basketball
  - High Jump
  - Ax Throwing
- Forces
  - Archery
  - Long Jump
- Energy
  - Trampoline
  - Pole Vault
  - Cheerleading
- Momentum and Impulse
  - Volleyball
  - Softball
  - Football
- Center of Mass of Extended Objects
  - High Jump
  - Football
  - Basketball
  - Cheerleading

a sport in which almost no one participates, but which demonstrates physics principles well.)

We also considered the ease of filming a real or almost real event. For example, a practice high jump with a fixed camera is identical to a competition high jump except that the camera crew does not need to worry about someone walking in front of the camera at a critical time. On the other hand, isolating a block in football is very difficult in competition and looks much different visually in a one-on-one practice situation.

Ease of measurement is another consideration. Students must be able to complete meaningful measurements from the video scenes. Thus, the important aspects of the event must be easily visible and measurements must be possible with rulers. Scenes which would require specialized measuring equipment, such as digitizing pads, were avoided.

Finally, we selected athletes who were very good in the sports involved. In addition to high-quality college athletes (including one NCAA champion) we were able to film high-school-aged athletes performing at the Junior Olympics National Championship. Thus, we were able to obtain quality performances of individuals with whom high-school physics students could identify.

The completed videodisc will contain a large number of lessons which could be used in a high-school physics class. Accompanying written material will provide details of the lessons for the teachers and worksheets for the students. All lessons will emphasize measurement and analysis; several will involve creating models of the athlete's motion and comparing these models with the actual event. One example of this modeling is presented in the following section.

ANALYZING MOTION WITH THE VIDEO

A method which would enable students to analyze the motion of athletes must take advantage of the medium as much as possible, but not use so much sophisticated equipment that most high schools would be unable to use it. Our method requires a videodisc player, a monitor, an acetate sheet, and a marking pen. Any videodisc player which has search and single frame step capabilities is sufficient. Thus, consumer-level players which have sold for as little as $200 can be used.

Students place the acetate sheet on the front of the monitor and mark the positions of the athletes with the pen. For situations in which time is an important variable, they also write the frame number next to each mark. These data can be recorded quickly and taken away to analyze, so one or two videodisc players could serve a normal sized physics class. (This type of interactive video was first used on a children's TV program, "Winky Dink and You," which aired during the 1950s. Thus, we have called this method the Winky Dink method of interactive video.)

The analysis of these data can be completed by traditional methods. However, we have used commercially available spreadsheets, such as Lotus 1-2-3 and

VisiCalc, for the analysis. The spreadsheets can complete the arithmetic quickly and can allow the generation of graphs for the students to consider and interpret.

MODELS OF THE HIGH JUMP

Anyone who has watched a high jump event has noticed the rapidly changing and seemingly very strange motions of the athletes. The most common technique of these motions is called the Fosbury Flop and was made famous during the 1968 Olympics in Mexico City. At that time Dick Fosbury set an Olympics record which far exceeds any increase which could be attributed to Mexico City's lower gravity and air density [14]. An example of this type of jump is shown in Figure 1.

For students to understand why this technique is useful they need to build models of the motion. From the models they can learn about the details of the motion, the reasons for certain parts of it, and the motion of the center of mass of the athlete. Models for this type of analysis are used commonly in biomechanics

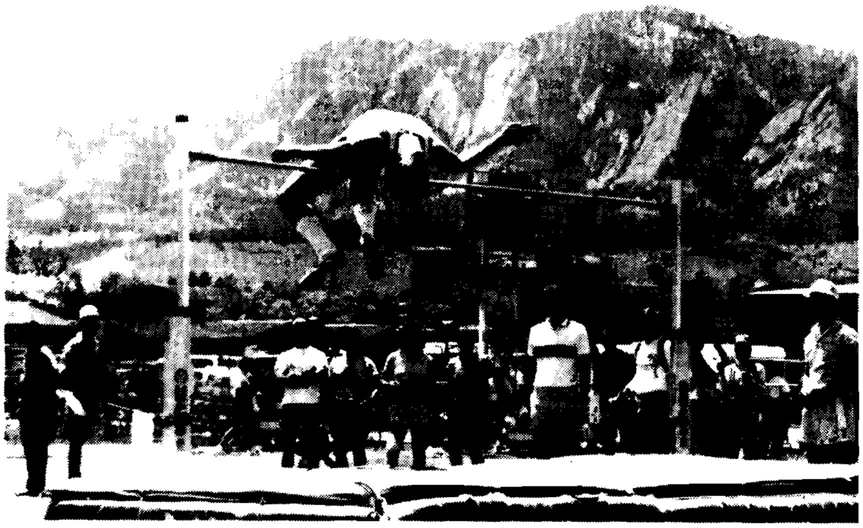

Figure 1. The Fosbury Flop was used in this high jump during the 1986 Big Eight Championship. (Photograph courtesy of the Kansas State University Department of Intercollegiate Athletes.)

and kinesiology [15]. In general, they involve the creation of a multi-segment stick figure to represent the athlete. Such stick figures are assumed to have a number of rigid segments with each of the segments having a mass which is determined by studies of cadavers. A common stick figure model of the motion has nine to eleven segments although some studies have divided the body into more than twenty rigid segments.

These stick figures represent a model of human motion. By using the model a student can look carefully at the motion of an athlete and apply the principle of physics to understand the complexities of the motion. However, the model with nine segments would be quite complex for students to use directly. Marking a large number of segments on the screen and determining the center of mass would involve so much tedious work that the student would lose sight of the physics involved.

To overcome this situation we have introduced a different approach to this situation. We ask students to use three different models of the high jumpers motion. Each of these models is much simplified version of the biomechanist's stick figure. They are presented in Figure 2.

The simplest model is a treatment of the athlete as a rigid body with uniform density (Figure 2A). The center of mass of the athlete is at the center of the body. A three-segment model (Figure 2B) is slightly more complex, while a five-segment model (Figure 2C) adds some more flexibility for describing the motion. For the three- and five-segment models each segment is assumed to have a uniform density. However, the percentage of total body mass of each segment is not identical. Instead, the fractions, which are assigned as indicated in the figure, are taken from cadaver studies [15].

With each of these models students analyze the motion in the video by using the method described above. They place an acetate on the screen and draw the model for each of the frames. Because they begin with the simplest model, they immediately see the limitation of it as a description of the motion. For example, the question of exactly where to draw the line representing the rigid figure immediately arises. "Do we draw from the top of the head to the foot or between two other points which do not move as much? Do we remain consistent and always draw between the same two points? What do we do when the feet are not together?"

Some of these problems are alleviated when the students move to the more complex models. They are able to bend the stick figure and, thus, more accurately portray the motion.

Next, the students address the value of making the model more complex by looking at the motion of the center of mass for each of the models. As shown in Figure 3 this motion shows a large change from a one-segment to a three-segment model, but much less pronounced changes between the three- and five-segment model. The students can then evaluate the value of the extra work in increasing the complexity of the model. As a final comparison they can compare their and kinesiology [15]. In general, they involve the creation of a multi-segment stick figure to represent the athlete. Such stick figures are assumed to have a number of rigid segments with each of the segments having a mass which is determined by studies of cadavers. A common stick figure model of the motion has nine to eleven segments although some studies have divided the body into more than twenty rigid segments.

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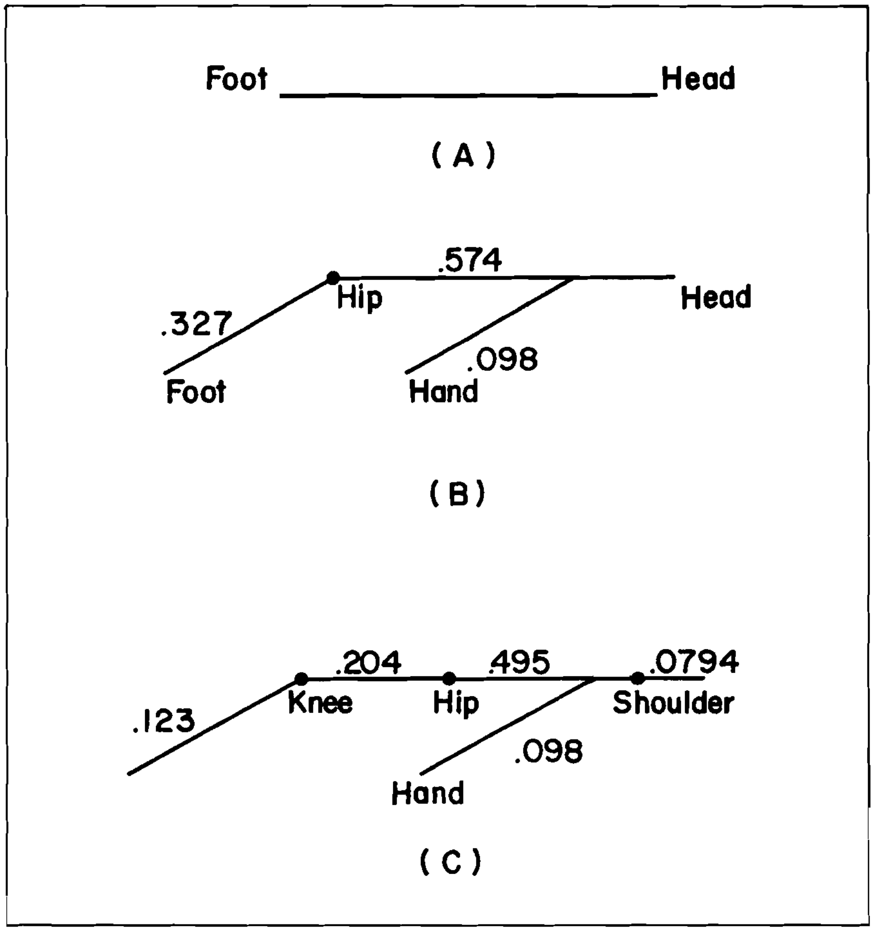

Figure 2. Students use the models of the athlete to analyze the motion of a high jumper. (A) The jumper is considered a rigid object with a center of mass at the center of the object. (B) The jumper is modeled as three rigid objects with the percentage of mass in each setment determined by cadaver studies. (C) A five-segment model is used to analyze the motion.

model analysis with that of a nine-segment model which was generated by digitizing various points on the high jumper's body. Again, they can consider the value of the increased effort needed to perform this analysis.

Because the "Physics and Sports" videodisc has not yet been pressed, this analysis has been completed by only a few students who used a videotape player with single frame advance. However, the results have been very encouraging.

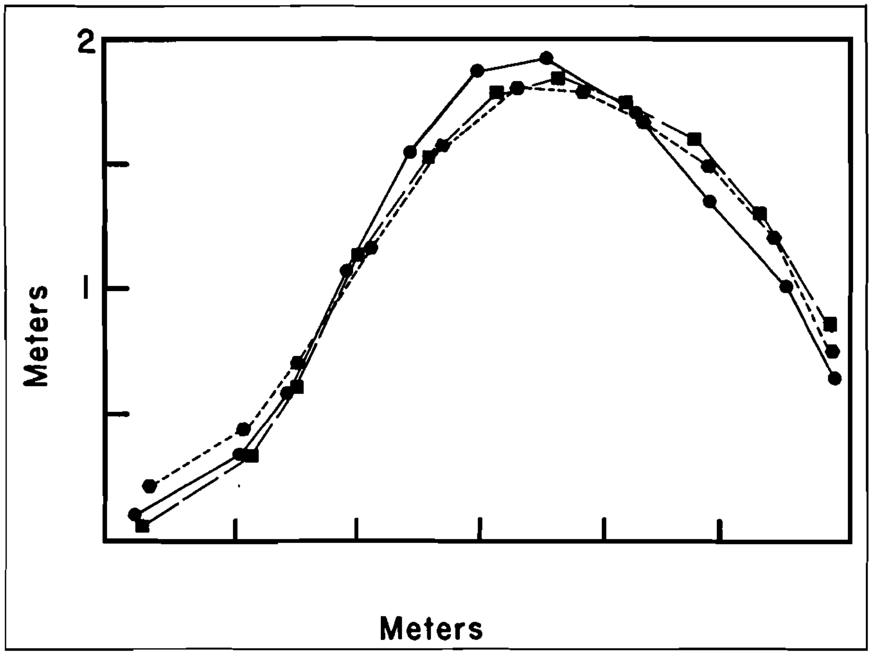

Figure 3. The motion of the high jumper's center of mass depends on the model being used. The circles and solid line represent the motion as determined by a one-segment model [Figure 2A]. The squares and long dashes are the motion determined by a three segment model [Figure 2B]. The hexagons are short dashed line show the center of mass motion using a five segment model [Figure 2C].

Students are able to draw the models and see the advantages and limitations of each one. In this way the students seem to be understanding some of the uses of model building in physics.

CONCLUSIONS

The use of interactive video to teach high-school physics students to develop models for motion is just beginning. However, we have seen that students can use the models to analyze the motion. Further, our relatively crude method of using the video with an acetate sheet and a marking pen seems to work well. While we have not tested it in comparison to a sophisticated computer overlay system, we feel that it might have some advantages. In particular, it provides the concrete experience of students actually drawing the model. The use of spreadsheets to treat the data and prepare the graphs has also proven very useful. We have no hesitation in asking students to prepare a different graph or complete further analysis because the time involved in such additional work is quite short. However, much knowledge of physics can be gained from it.

Because this method requires a minimum of equipment in addition to that already available in the typical high school, we hope that this approach to interactive video will increase greatly the number of schools involved in this type of activity.

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