Bicycle physics as a field activity

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Abstract. In the mechanics laboratory course of the first year of University, we are introducing outdoor experimental activities at the university campus. Since bicycling inside the university campus has been promoted by authorities, our students have an excellent opportunity to learn the kinematics of bicycle physics by riding a bicycle as a real experience. For this purpose, we have designed a simple kinematics activity to be carried out in the sports fields of our university. In this work, we describe the movements on the bicycle made by students and the interpretations of students in the laboratory session.

1. Introduction
In physics education, experimental teaching is necessary to have a complete process of student learning. Usually, teaching of experimental physics is carried out in laboratories where complete equipment, instrumentation, and material for several kinds of experiments are ready to be used. But these requirements are not always given.
Even when a laboratory has a complete set of equipment and instrumentation for measurement and enough materials for experimentation, in order to have a good learnings of physics, it is necessary to have a good strategy of teaching of physics, because often the students complain about how physics is taught in the experimental activities (very often called cookbook recipes by several teachers and students), that are carried out in the laboratory. Other students’ complaints are that physics experiments in laboratory never go well and the physics taught in the laboratory (and also in theoretical classes) is well-applied only in the laboratory but not outside it. Physics of daily life is different from physics in school classrooms or laboratories. Teachers need to apply creative strategies in their experimental teaching to avoid that students finish the laboratory course with this kind of ideas.

With physics freshman students, for whom mechanics laboratory course is their first laboratory, it is not easy to start with very creative experimental activities, because students have no experience in experimental work and the first purpose of the laboratory is to create some skills and abilities in the students for the acquisition of experimental techniques. At the same time, teachers must work in the mediation of building conceptual physics knowledge in students that they can apply in their experimental activities, at a pace, that students can keep without complications and at which they can understand all the steps very well. That is the challenge of physics teaching.
2. Experimental activities outside the laboratory

After an introduction of measurement theory in the mechanics laboratory course, the next topic is kinematics that covers uniform and uniformly accelerated movement of a body. There are different kinds of strategies to teach kinematics inside the laboratory but the strategy that we are working with our students is outside the laboratory with activities that we have called field activities of physics.

The activity that students do outside the laboratory is the study of the bicycle kinematics. This activity is supported by the knowledge that students have of kinematics from their theoretical course of mechanics. In this course, students have been learning the equations of the kinematics of the movements with constant speed and constant acceleration, with solving problems as exercises to apply that knowledge. In the laboratory, the focus is to study the same concepts but in an inductive way, considering the intuitive knowledge that students have about the motion and to test that knowledge in the field. We now describe the strategy that we followed to carry out the study of the kinematics of the bicycle’s movements.

3. Teaching strategy

The strategy began with a talk at the laboratory with students, the teacher and his assistant about the movements on a bicycle. The talk began by asking who knew how to ride a bicycle. Several of the students knew to ride a bicycle, but others did not, and this gave us the opportunity to separate into two groups the students: the group that could ride a bicycle and the group that measured the movements.

With both groups, we discussed how to ride the bicycle with uniform motion or with uniform accelerated motion and the “experts”, who knew to ride a bicycle, said that if a bicycle were to be ridden at a steady pace, the bicycle could go at a constant speed, but if the bicycle was ridden from rest with a “strong” rhythm, the bicycle could go with constant acceleration, and if the bicycle was moving with some speed and it is suddenly stopped, the movement of the bicycle would be slowed down.

With this empirical knowledge about how to ride a bicycle, students accepted the following hypotheses that must be investigated:

- **Hypothesis 1.** A bicycle that is ridden at a steady pace goes with constant speed.
- **Hypothesis 2.** A bicycle that begins its movement from rest that is ridden with a strong pedalling rhythm moves with constant acceleration.
- **Hypothesis 3.** When a bicycle that moves with constant speed suddenly stops, the movement of the bicycle slows down.

After students had hypotheses to be investigated, the whole group discussed how to measure outside the laboratory several movements on bicycles. It was easy to propose a way to make this experimental activity outside the laboratory because inside the campus of our University, students can borrow a bicycle at no cost and ride it on the entire university campus for a limited time. The next step was to select the exact location where execute the activity. This location was the football field of our University, with a flat surface very convenient to be ridden on a bicycle.

With the group in charge of measuring, it was discussed how to make the measurements of the movements of the bicycle. The video technique was selected as a technique to capture experimental data and then as a technique to do measurements. To this end, it was necessary to place marks on the floor at equal distances in order to have a line that would serve as a reference system for the straight-line movements that students would make with the bicycle. With all this planned, the whole group went to the football field to carry out the experiments of bicycle motion and then came back to the laboratory to do the analysis of the movements with a software to capture videos and a spreadsheet to analyze data, and to prove hypotheses.

4. The experimental field activity

Besides the bicycles for the experimental activity of bicycle motions on the football soccer field, different kinds of equipment and materials were necessary to take from the laboratory to the experimentation field (cam recorders with a telephoto lens, tripods, 30 m measuring tape, Styrofoam cups, red flags, and sand).
We needed to ask permission from our Faculty of Science authorities to take this equipment and these materials from the laboratory.

While the cyclists practiced movements on the bicycles, the group of students in charge of the measurement put marks on the floor with white polystyrene cups filled with sand that can be used as marks to the video film, and prepare at the distance, the video equipment with cameras with telephotos on tripods to take video at 30 fps of the bicycles motions. The line of movements with marks, perpendicular to the optical axis of the cameras, is located in front of the cameras at 30 meters distance and the cyclists move behind this line.

Three types of movements were planned to be executed by cyclists:

- A cyclist moves in a straight line with a constant rhythm in a positive and negative direction at the same time.
- Movements of the cyclists that start from the rest, in a straight line, with “strong” rhythm, in a positive and negative sense at the same time.
- Movements of the cyclists that go at a constant speed, in a positive and negative sense at the same time and suddenly stop their motion.

4.1. Capture and analysis of the movements

The video was recorded continuously without stopping the movement of the cyclists. In the reproduction of movements of cyclists made with the Quicktime software, small video clips were cut to capture data with Tracker (free video analysis software that is very useful to capture data from video clips and graphically analyse data points).

Students in small groups of three (including the cyclist student) captured data from the video clips by using Tracker, transferred them in a spreadsheet (e.g. Microsoft Excel) for graphical analysis and for fitting equations that model the movements.

4.2. Examples of movements

A movement of a cyclist student with constant speed (Figure 1). The positive direction is from left to right, but the cyclist is going to the left, so in this case, the movement is with negative velocity.

![Figure 1. Movement of cyclists with constant speed. Every third frame of the original recording is shown, that is at 10 fps.](image)

The next movements are two cyclist students with constant speed traveling in the positive direction on parallel tracks (figure 2).
Figure 2. Movement of two cyclists with constant speed in the same direction. Every third frame of the original recording is shown, that is at 10 fps.

The third movement is a cyclist student going at constant speed braking suddenly and very strongly (figure 3).

Figure 3. Movements of a cyclist with constant and negative acceleration in the positive direction. Every third frame of the original recording is shown, that is at 10 fps.

The last movements are two cyclists, one moving to the right with constant negative acceleration, and the other cyclist going to the left with constant negative velocity.

Figure 4. Movements of two cyclists, one with constant negative acceleration in the positive direction and another with constant negative speed. Every third frame of the original recording is shown, that is at 10 fps.

5. Analysis of movements
In this work, we present the analysis of four different video clips taken in the field activity of bicycle kinematics and shown in Figures 1 to 4. If the movements are analyzed separately without regard to the time when they occur, they will be represented graphically in a traditional way with only one movement in the graph. If we consider the sequence of movements in time, a correct analysis must take this into account. As shown in figure 5, the students have a time series of movements.
Fig. 5. Time series of bicycle movements of six cyclists are represented over time.

In figure 5, the x,t-graph of six movements corresponding to figures 1 to 4 are depicted showing all the characteristics of the movements. Some descriptions given by students of the movements shown in figure 5 are the following:

- Cyclist 1 goes with constant speed in a negative direction.
- Cyclist 2 goes with constant speed in a positive direction.
- Cyclist 3 goes with constant speed behind cyclist 2.
- Cyclist 4 goes with constant speed and slows down suddenly.
- Cyclist 5 goes at a constant speed and increases the speed.
- Cyclist 6 accelerates at a constant rate in a negative direction and then follows its movement with constant speed in the same direction.

The exact description of the movements in figure 5 is given in table 1, with equations that correspond to the movements of each curve in this figure.

Table 1. Equations corresponding to the movements of the cyclists analyzed. Some of these movements are compound movements and have two equations to describe them.

| Equation | Description |
|----------|-------------|
| \( x_{B1} = -6.5t + 16.4 \) | First movement |
| \( x_{B2} = 4.5t - 15.1 \) | Second movement |
| \( x_{B3a} = 3.7t - 18.3 \) | Third movement a |
| \( x_{B3b} = 4.5t - 23.3 \) | Third movement b |
| \( x_{B4a} = 6.2t - 47.5 \) | Fourth movement a |
| \( x_{B4b} = 0.5(-6.1)t^2 + 54.4t - 237.9 \) | Fourth movement b |
| \( x_{B5a} = 5.1t - 61.0 \) | Fifth movement a |
| \( x_{B5b} = 6.1t - 60.1 \) | Fifth movement b |
| \( x_{B6a} = 0.5(-1.3)t^2 + 12.8t - 46.5 \) | Sixth movement a |
| \( x_{B6b} = -5.6t + 82.4 \) | Sixth movement b |

In table 1 the equations of the movements corresponding to figures 1 to 5 are shown. Equation \( x_{B1} \) represents the first movement, equation \( x_{B2} \) represents the second movement, equations \( x_{B3a} \) and \( x_{B3b} \) represent the third movement, equations \( x_{B4a} \) and \( x_{B4b} \) represent the fourth movement, equations \( x_{B5a} \) and \( x_{B5b} \) represent the fifth movement, and equations \( x_{B6a} \) and \( x_{B6b} \) represent the sixth movement.

6. Discussion

After the experimental activity is finished, data capture, processing, and analysis began at the laboratory. Students had another class and five days between classes to do these activities, and a week more to show their results to all the group. In the general discussion, the different kind of movements examined are put together as they are presented in this paper.

The graphical representation of the movements was not difficult to do by students, because they have several experimental elements that guide their thinking to see the complete video of the movements leading their graphical representations. Motion in the video is very similar to real movements, but with the advantage that students can manipulate it frame by frame forward or backward. Tracker software can show simultaneously the movements of the cyclists with their corresponding x,t-graphs.
This dual observation creates a new feeling in students’ thoughts about how to interpret a movement that can follow step by step in the motion video and simultaneously get the graphic of this movement. The conceptual thought of a student is being constructed while watching the video alongside the graphic representation. That is better than any explanation of the same movement.

As an example of this affirmation, we have the last movement in figure 4 and figure 5. In figure 4, this movement begins at the right side of the track with zero initial velocity. The cyclist accelerates in the negative direction increasing the speed of the bicycle, but in the negative direction, then the cyclist keeps the speed constant. In figure 5, the $x,t$-graph of this movement is a curve that begins with a zero slope of the tangent to the curve, as the movements go on, the curve decreases with constant acceleration (as could be deduced from the tangent to the curve representing a decreasing speed) and then the movement follows with constant speed given by the negative slope of the straight line.

This dual interpretation could be contradictory for some students, because in the graph, the curve is decreasing with time. If the same student compares this movement with the other movements, they will find that this graphic interpretation is due to the orientation to the left of the movement, while the frame of reference is positive to the right.

It is more difficult for students to build Table 1 with the abstract equations of the movements analyzed. The first curve of the graph in figure 5 is the least difficult for students because the movement begins at the beginning of the time, however, the initial position is at the right to the origin of the frame of reference, that is a small problem to understand by students. But in Tracker and Excel, it is possible to use the linear and quadratic least square fitting of straight lines and quadratic curves respectively. Students are helped with these mathematical tools of the software to find the equations of the movements.

The mean focus of this procedure is the discussions and interpretations that students can do of the equations and not necessarily the mathematical construction of these equations that change the physical discussion to a mathematical discussion. (This discussion is done in the theoretical class of mechanics and in the laboratory. We only apply the results of this discussion for the sake of clarity of physics of the complete activity).

7. Conclusions
We have found several advantages of the field activity of the kinematics of the bicycle. Perhaps the most important was that the students’ interest in studying kinematics was increased enormously compared to the same activity carried out in the laboratory with previous groups of the same class of laboratory of mechanics. With this new attitude towards the activity outside the laboratory, the students have the opportunity to show their competences in different steps of the scientific process and from answering the initial questions.

The three hypotheses that students proposed previously for the experimental activity were supported by the analysis of the data and the mathematical equations that they found to model these movements. This success gives students the confidence to approach new research based on experimentation. Students developed several thinking skills to relate the real movements to their graphical and mathematical representations and vice versa, acquiring a better understanding of the kinematics of the movement and its conceptual framework.

Students’ thinking changed from concrete thought to more abstract thought, but without loss of the inverse process of thinking, from the abstract to the concrete, which we evaluate when we ask students to reconstruct the real movement from an abstract equation. We know that this process of thinking is not fully developed in students with this field activity, but the realization of this scientific activity with such successful results gives the confidence to students to put in practice this scientific methodology to study new phenomena regardless of if their researches are inside or outside the laboratory.
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