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Three years evaluation of a teaching learning sequence on rolling motion based on a blended learning environment

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Abstract. As highlighted by research, students have difficulty in understanding the physics of rolling motion and the role that sliding friction forces have in it. Physics courses at high school and introductory university level do not usually handle the subject with the attention it deserves. Textbooks often only show particular rolling examples instead of providing a general treatment of the underlying physics. Therefore, students can develop misunderstandings that lead to errors when approaching general problems. In 2014 we have designed a teaching learning sequence (TLS) rooted in previous research about student conceptions, centred on the role of friction in different cases of rolling. A series of experiments based on video analysis integrated with interactive simulations were used to emphasize key concepts and to motivate students in their exploration of the subject. The activity sequence was designed for undergraduate students or advanced high school classes. In this paper we report novel results from three years of testing and refining the teaching sequence at both the Universities of Pavia and Trento.

1. Introduction

Rolling motion is a fundamental physics topic, included in all introductory courses. Nevertheless, the students' understanding of this topic is frequently quite limited and unsatisfactory, as several studies have shown. Many researchers have investigated common student difficulties in approaching rotational and rolling motion [1–3], indicating that these problems are independent of students' background. Other researchers tried to explain the main characteristics and crucial details of rolling motion [4-11].

Starting from research results, we developed an activity sequence designed to address students' difficulties as well as to help students acquire the elements of an explanatory model for the complex phenomena involved in rolling motion [12]. The TLS aims at:

a) clarifying "step by step" the role played by sliding friction forces in different cases of rolling motion, i.e. using the role of friction as a scaffolding idea to organize students' knowledge;

b) creating a blended learning environment combining tabletop experiments, video analyzed experiments and computer simulations.

In this work we report novel results from three years of testing and refining this teaching sequence at both the Universities of Pavia and Trento. During these years the sequence was modified according to the cycle of design, implementation, evaluation and redesign (see figure 1).

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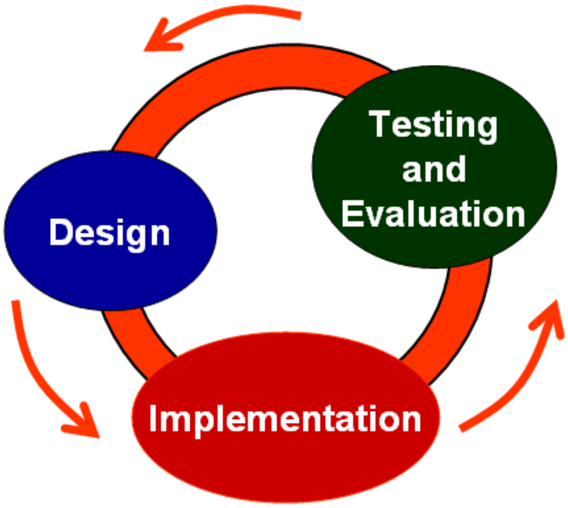

Figure 1 the cycle of design, implementation, evaluation and redesign: the initial TLS, rooted on a careful textbook analysis and on research results on students' difficulties, was modified according to the results of previous testing.

The resulting TLS alternates simple tabletop experiments; video-based experiments (enhanced with slow motion techniques available on smartphones) analyzed using the open source software Tracker; and simulations, designed by students themselves, using the free software Algodoo (see figure 2).

Figure 2 Examples of activities: tabletop experiment about the friction force, Tracker video analysis of a rolling motion, Algodoo simulation.

We made a few fundamental decisions regarding the design of the teaching sequence which can be summarized as follows.

- Students perform the experimental activities in small groups.
- Students are engaged in the "step-by-step" process of constructing a qualitative model that they can use to predict and explain the behaviour of rolling bodies.

In the last three years the sequence has been tested at both the Universities of Pavia and Trento, in all cases with undergraduates who had previously studied rolling. On the whole, the activities were tested with 65 undergraduates who performed the experimental activities in groups of three and completed the experimental work in three sessions of 2 hours each.

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2. Recent improvements

2.1 The physical contents

Schematically, the sequence proceeds through the following steps [12]:

a) the pure rolling condition and the kinematics of rolling motion in different frames of reference;

b) the role of friction in rolling motion at constant speed;

c) the role of friction force in leading an initially sliding object to roll;

d) rolling on an inclined plane and the threshold value of friction force for maintaining pure rolling motion;

e) direction of the friction force on a wheel or cylinder accelerated by a torque, or by a force at variable distance from the center of mass;

f) collision of rolling objects and the role of friction in transferring kinetic translational energy in rotational energy and vice-versa.

According to the methodological approach described above we worked to restructure the organization of the contents and to include two new parts in the sequence: an initial experimental activity on static and kinetic sliding friction; and a final one on rolling motion on horizontal plane under an external force. The most significant improvement from an experimental point of view is given by the use of high speed camera (240 fps) which makes it possible to analyse in detail the short time interval of collision.

In the sequence a case study is proposed as motivating problem and inquiry activity. We asked students to compare the elastic collisions of two carts on a guide and two rolling spheres. Students are invited to explore several variants of the experiment by designing and manipulating Algodoo simulations. At the end of these activities students can analyse the real experiment, investigating what happens in the few milliseconds after the collision, as Figure 3 shows.

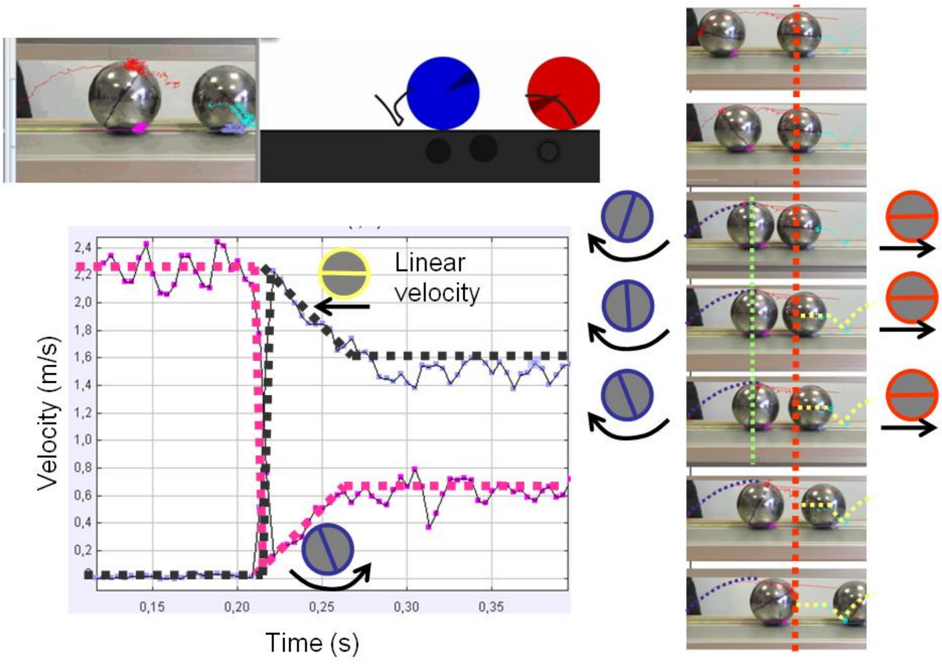

Figure 3 Tracker video analysis of a video acquired at 240 fps. The collision between a projectile rolling ball and a target ball is characterized by a rapid phase (50 ms) where the linear velocity of the projectile is reduced while the target ball start rotating and then starts a rolling motion. The frames clarify this phenomenon.

2.2 Students' understanding analysis

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Main research question of the study has been, since the beginning, the following: does a teaching learning sequence on rolling motion based on multiple teaching strategies and ICT tools provide significant educational advantages?

Recently we have addressed a more focused research question: can such a teaching learning sequence help meet objectives of long-time concept retention? In order to answer such questions, we use a combination of evaluation instruments:

a) a pre-test before the beginning of the sequence, composed of multiple choice items only, some of which based on previous research [1-3];

b) a post-test given at the end of the sequence, containing both multiple choice items and open response items;

c) a delayed post-test given about three months after the end of the sequence.

Multiple choice questions of the pre-test and post-test are taken (see ref [12]) from standard conceptual inventories to make it possible a comparison with results from other studies [1]. In the final version, both the pre-test and the post-test contain six multiple choice items. In order to render the results comparable, pre-and post- test items are placed into five conceptual strands:

A. Rolling and frame of reference
B. Threshold value of static friction force
C. Rolling on the horizontal plane role of friction and other parameters
D. Rolling on an incline
E. Rolling and slipping motion: work done by the friction force

Two open response, explanation-type questions were introduced in the 2016 post-test for both Pavia and Trento in order to evaluate the quality of students' argumentative discourse. The first question required students to predict, providing an explanation, whether total mechanical energy and momentum would be conserved in a collision between a sphere, rolling on a plane with friction, and a cube initially at rest on a plane with no friction. The second was an explanation type item, requiring students to explain why a yoyo, lying on a horizontal plane and pulled horizontally through a string wound around a spindle of smaller diameter than the yoyo itself, rolls in the direction of the pulling force, rather than in the direction that would be predicted by considering the torque produced by it.

In 2017 a post-test item was added, asking students to rate on a scale from 1 to 10 the importance of each of the following methods or approaches used in the sequence in promoting their understanding: a) tabletop experiments; b) Tracker video analyzed experiments; c) Algodoo simulations; d) mathematical arguments or proofs and e) qualitative and conceptual explanations of phenomena.

In 2016-17 a delayed post-test was performed for both Pavia and Trento three-four months after the end of the sequence. The delayed post-test was again on the same concepts tested in the pre-and post-test, and composed of four questions identical to ones of either the pre- or the post-test, and of two new ones.

3. Results

As already mentioned, the sequence was tested with a group of 65 undergraduates. During their previous studies they attended at least two courses on mechanics, a first introductory course on Newtonian mechanics, and a second one on Lagrangian and Hamiltonian mechanics. The programs of these courses include static and dynamic friction forces and their role in rolling motion.

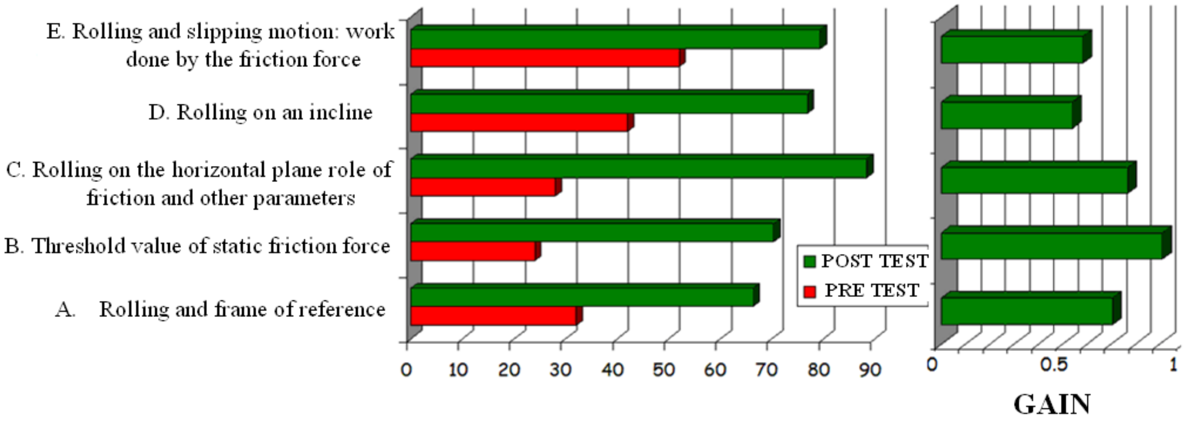

Figure 4 Pre- and post-test results for items related to the same concepts and the corresponding Gain factor.

In figure 4 we compare pre- and post-test results for items related to the same concepts. On the whole, in the post-test the percentage of incorrect answers was, below 25%. This result alone is an indication that the sequence created a fruitful environment for the students' learning, enabling them to address their initial difficulties.

To analyze the students learning progress during and at the end of the instruction, we evaluated the fractional increase in percentage of correct answers, called Gain or g-factor. The normalized Gain [14], is

$$\text{Gain (g - factor)} = \frac{S_f - S_i}{100 - S_i}$$

where S_i and S_f are the pre- and post-test scores expressed as percentages. The value of the Gain ranges from 1 (when a student gets all the problems right on the post-test that she or he missed on the pre-test) to 0 (student shows no improvement from pre- to post-test) or even negative values (student misses more questions on post-test than pre-test).

This parameter has become the standard measure for reporting scores on research-based concept inventories. Notice that the Gain in our case is always larger than 0.5.

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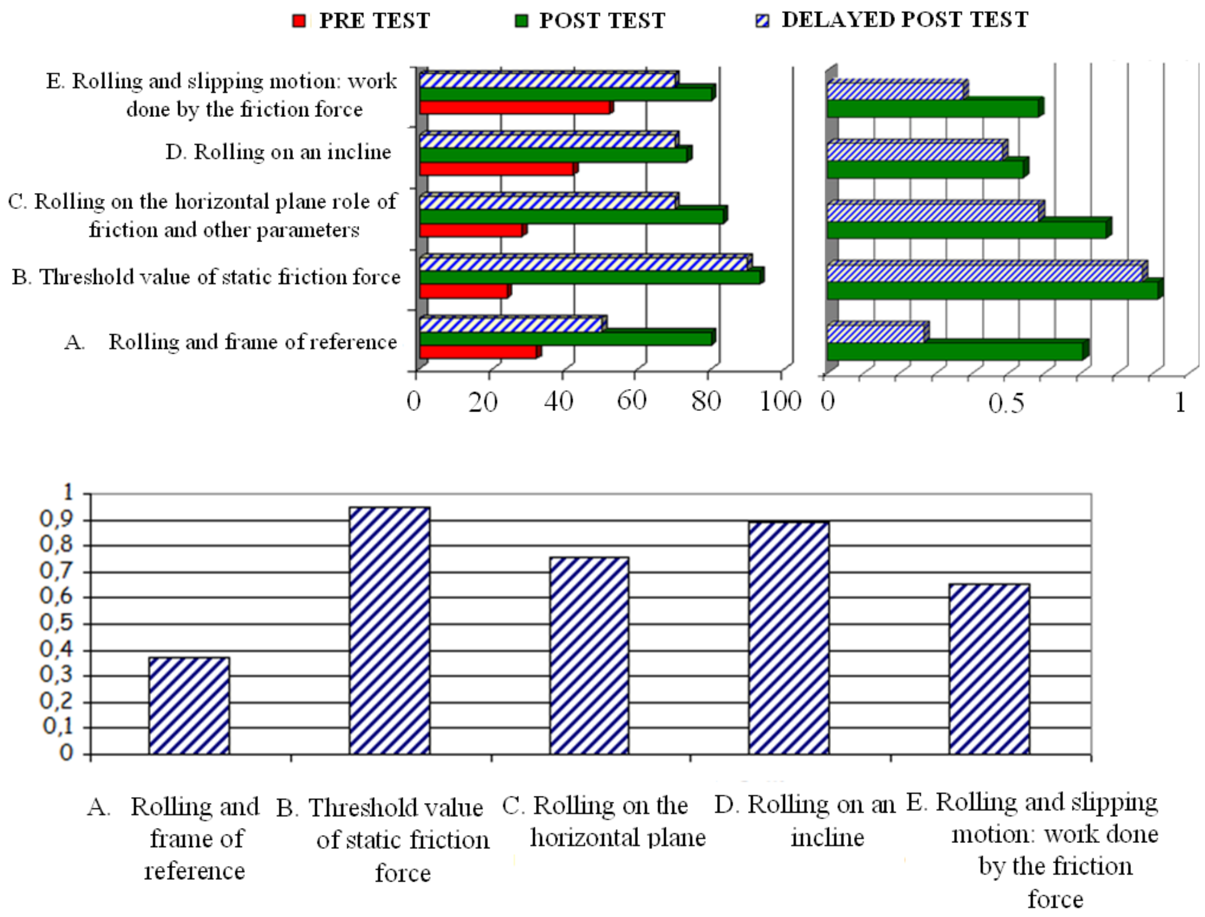

Figure 5 Pre- post- and delayed post-test results for items related to the same concepts and the corresponding Gain factor corresponding to the post and delayed post test. (Bottom) The Retention

In figure 5 we compare pre-test, post-test, and delayed post-test results for items related to the same concepts. The Gains respect the pre-test confirm the effectiveness of the sequence but also show a reduction of the Gain between the post-test and the delayed post-test. This is quite evident for the *Rolling and frame of reference* item where the Gain in the post test was 0.7 and the Gain in the delayed post test is 0.2.

Following Hake's idea, we define a new quantity analogous to the Gain that we call Retention,

$$R = \frac{S_{Delayed} - S_{Pre-Test}}{S_{Post-Test} - S_{Pre-Test}} = \frac{G_{Delayed}}{G_{Post-Test}}$$

As it is shown in figure 5 (bottom), the retention is always smaller than 1, with a minimum value (0.35) for the item concerning *Rolling and frame of reference*. For other items R is above 0.9 showing that some concepts are and remain in the *knowledge repertoire* of the students.

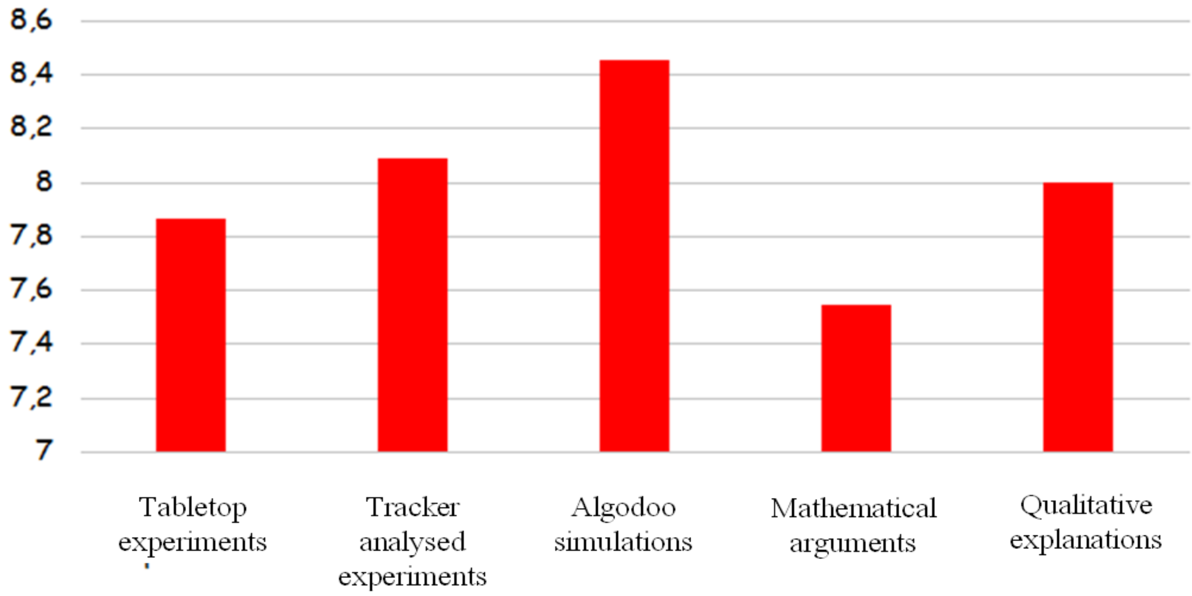

Figure 6 Results of the item concerning the importance of each of the methods or approaches used in the sequence in promoting students understanding

In conclusion, we underline the results of the item concerning the importance of each of the methods or approaches used in the sequence in promoting student's understanding. Algodoo simulations are considered the most relevant method. This result shows the effectiveness of the inquiry approach promoted by Algodoo simulations, but may also suggest the importance of experimental activities to motivate students' autonomous work with simulations and to orient their inquiry to relevant aspect of the problem. Notice that qualitative and conceptual explanations of phenomena are better considered than mathematical arguments or proofs.

4. Conclusions

A sequence of activities on rolling motion and friction forces was designed and tested with a group of 65 undergraduate students in Physics and in Mathematics at the University of Pavia and Trento. A learning environment combining table-top experiments, video analysed experiments and computer simulations was used to study situations in which the relationship between friction and rolling is especially complex, or leads to counterintuitive results. Integration of different tools provided the ideal environment for a guided enquiry activity. Comparison among pre-test, post-test and delayed post-test results shows that students obtained stable sensible improvements, and overcame many common difficulties.

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