Training teachers to use playgrounds in physics teaching

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Abstract. Climbing racks, carousels, swings and slides can be used for many experiments and demonstrations that offer surprising results, often challenging students' understanding of motion. This paper describes activities used in professional development workshops for teachers on the use of playgrounds in physics teaching. Toys and other simple equipment complement the experience of the body. In addition, smartphones can be used both for documentation and measurements. The activities emphasize how playground experiments can connect very concrete experiences of acceleration and force to textbook examples and fundamental physical principles.

1. Introduction
Playgrounds are full of classical physics demonstrations waiting to be performed. The slide is an inclined plane [1,2] and swings [1,3] provide pendula to study forces and oscillation periods. Even in the smallest playgrounds, there are places to climb where you can drop different objects and compare how they fall [4]. Larger playgrounds may have carousels [5,6] and trampolines [7-9]. Many experiments and demonstrations give surprising results, challenging the understanding of motion. Playgrounds also offer useful preparations for physics activities in amusement parks [10].

The body in Newton's second law need not be an inanimate object - the forces in accelerated motion can be felt throughout the body. The forces acting on and within the body can be visualized with toys and other simple equipment, while smartphones enable data collection of the forces [11,12]. In addition, video recordings can be analysed to give an outside view of the motion, which can be explored using apps such as Tracker [13] or Logger Pro 3[14]. The external view of motion is further explored in a wide variety of situations in the Playground Physics app for iPads and accompanying educational material from the New York Hall of Science [15].

For a number of years, we have run professional development workshops for teachers on the use of playgrounds in physics teaching. During these events we emphasize how the experience of the body is related to fundamental physics concepts. In particular, we support the discovery of situations where mass does not influence motion [4], due to the equivalence between inertial mass (in \(m_a\)) and gravitational mass (in \(m_g\)) - the equivalence principle.

2. Falling objects
Dropping objects of different size and mass connects back to Galileo's legendary experiment from the tower of Pisa. In earlier work [4], we presented examples of 11-12-year olds who were asked by their teacher to consider about what factors may be important for the time required to reach the ground. Comparisons were planned between pairs of object where e.g. mass, area or density were kept constant, while other factors vary. A slow-motion app provided the class with the possibility for shared observations and discovering the influence of the air. The result is surprising to many non-physicists, who may need to film the motion or lie down to observe objects landing together (figure 1). Higher
climbing racks or climbing nets allow for more spectacular demonstrations. The experiments may be used as a first introduction to the equivalence between inertial and gravitational mass - where mass doesn't influence motion [4,5,16].

Figure 1. Examples of experiments on falling objects (a-b) and inclined planes (c-d). (a) Preschool teacher lying down to get a better view of the landing of two objects dropped together. (b) Watching a slinky fall from a climbing net. (c) Measuring the inclination where a block starts to move down an inclined plane. (d) Comparing the motion of objects of different surfaces and different mass.

3. Investigating friction on an inclined plane
What factors influence how fast something slides down an inclined plane? Already preschool children are aware that raingear gives fast rides on wet slides and they may also be able to use the word friction. During teacher workshops, a brief brainstorm typically leads to the following factors: Slope, length of slide, clothes, surface material of the slide, water on the slide, sand on the slide, size of the contact area, mass of the object. These factors can then be investigated, and some eliminated.

What would teachers like their students to learn about friction? To help teachers develop a deeper understanding of friction we show them results of investigations by a group of 11-year olds [3]. The pupils had been asked to bring three types of clothes to a large slide. Their teacher had also prepared simple inclined planes from bookshelves, and prepared four blocks covered in different materials. The video abstract to the paper [3] shows how the pupils first focused on measurements but then, after a bit of prompting, shifted to comparisons (Figure 1 c-d). The video also shows the pupils discovering that neither mass nor the size of the contact area had significant influence on the motion. During the investigations, uncertainties were discussed and experiments repeated to help the participants to develop a sense of whether small differences observed were important and reproducible.
In the follow-up class discussions a few days later, the 11-year olds discussed that the effect of water on a slide is different for jeans and rainwear, and that sand has different effect on a slide and on an icy road: Friction depends on the properties of both surfaces and what is between them. The 11-year olds made use of their investigations on the inclined plane in their discussions of what happened on the slide, recalling that mass did not play a role in most cases. They concluded that "Friction is complicated". We have found that teachers are usually surprised about the many aspects of friction revealed in these discussions by the 11-year olds: there is more to friction than the relation $F_{fr} = \mu N$! At this stage, teachers may enjoy the delightful interview with Richard Feynman who talks about his father discussing the difference between knowing the name of something and knowing something.[17].

4. Rolling on an inclined plane

Investigating objects rolling down a slide can be made into a useful inquiry-based learning experience. The participants are first asked to write down a list of possible factors affecting how fast balls roll down the slope and then think of ways to test their hypotheses (figure 2). If the participants suggest that the "material of the ball" is important, they may need some guidance to distinguish between density, elasticity and surface properties, e.g. The participants are then encouraged to find ways to exclude some factors, in an approach inspired by methods from ISLE - Investigating Science Learning Environment [18].

Alternatively, the participants may be challenged to find pairs of balls rolling down together. Most often they need several experiments to be convinced that neither density, nor size of the ball influences the motion (figure 3) - another consequence of the equivalence between intertial and gravitational mass.

Figure 2. A selection of balls used for investigations of what factors influence how fast a ball rolls down an inclined plane
Having established that the mass, itself, is unimportant, adding balls with air inside leads to new challenges. These can be discussed in relation to pirouettes on ice, for groups where angular momentum and moment of inertia are not familiar concepts. Before attempting this investigations, participants should be familiar with conversions between potential and kinetic energy, e.g. in connection with swings.

5. Pendulum motion on a playground: Period, forces and energy
Swings on a playground offer rich opportunities to investigate forces in accelerated motion [1]. "Twin-swinging", where two swings move together, can be used to introduce the concepts period, amplitude and phase. Twin-swinging with an empty swing illustrates the independence of mass for motion driven only by gravity [4]. By standing up, the influence of pendulum length on period can be observed. Bringing a bottle, half-filled with liquid, challenges the understanding of acceleration. [1,3,16,19]. A little slinky can give a visual measurement of the forces felt by the body of the person on the swing [1] and smartphone sensors can capture both forces and angular velocities [11,12,19].

The pendulum is a common illustration of energy transformations, with energy transformed back and forth between potential and kinetic energy, and slowly dissipating into heat. Pulling the swing close to your chin and letting it go (figure 4) is a playground version of a classic lecture demonstration [20]. Holding your head still as the swing moves towards you requires some practice even if you trust physics.

6. Large playgrounds: Carousels and trampolines
Swings, slides and climbing frames are found on most playgrounds. Larger playgrounds may also offer e.g. carousels and trampolines.

Small carousels on a playground give opportunities for classical investigations of angular momentum and moment of inertia, by shifting the position of the body as the carousel moves. Other investigations are less well known: A slow-moving carousel can be used to illustrate the Foucault pendulum, by swinging a small object on a string as the carousel moves [5,6], relating to the question "How do we know the earth spins around its axis". Throwing a ball to a person on the other side of the playground carousel may also be feasible.
An idealized description of trampoline bouncing involves a combination of free fall and harmonic motion [7,8]. The mathematical description can be used to analyse e.g. the 2012 Olympic gold medal routine by Rosannagh MacLennan [21]. This has been found to be a rewarding exercise for students. A recent paper presents responses and discussions by student relating to this challenge [9].

7. Discussion
This paper has shown several examples of experiments on a playground that illustrate fundamental physical principles and phenomena, in particular the equivalence between gravitational and inertial mass. A youtube playlist [22] shows a group of teachers performing some of the experiments as part of a physics course. The difficulty of the experiments can be adapted to teachers and pupils or all ages. Workshops based on some or all of these experiments have been run for teachers from preschool to high-school. The paper summarizes typical teacher discussions in connection with professional development workshops. In facebook groups, teachers can then continue to share experiences and questions arising, and obtain support for their investigations.

![Figure 4](image_url). The author using a playground swing to illustrate energy conservation as an easily accessible version of a classic "Bowling ball pendulum swings back to nose" demonstration. The second image shows frame-by-frame positions of the swing obtained using Logger Pro 3 [14].

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