Amusement parks, playgrounds and the equivalence principle – Physics for the whole body and a smartphone or small toys

Ann-Marie PENDRILL

Department of Physics, University of Gothenburg, SE 412 96 Göteborg, Sweden
National Resource Center for Physics Education, Box 118, SE 221 00 Lund, Sweden

Abstract. What your body feels in swings, carousels or rollercoasters is related to the forces required to change motion. These forces can be visualized with small toys or be measured by a smartphone accelerometer, giving data that can be analysed in the physics classroom. The embodied experiences, as well as accelerometer data, depend on the equivalence between inertial and gravitational mass, which often leads to surprising consequences, that can deepen the understanding of Newton's laws. The poster will present a number of visual examples of experiments, demonstrations and analyses that challenge incomplete understanding.

Introduction

Do you remember what it feels like in the lowest point of a swing or pendulum ride moving back and forth? Do you remember what it feels like moving through a tight turn, over a hill or through a valley in a roller coaster?

The experience of the body is often omitted in physics teaching, possibly for fear of confusing students. On the other hand, what your body feels must be related to the forces required to changes in motion – acceleration [1]. The forces experienced by your body can also be measured by an accelerometer, e.g. in a smartphone, giving data that can be analysed in the physics classroom. [2-4]. The poster will present a number of visual illustrations of the equivalence principle and examples of how these experiences can deepen student understanding, as described in more detail in several publications..

The Equivalence Principle

The equivalence between inertial and gravitational mass leads to a challenge: Without external reference acceleration can't be distinguished from a gravitational field. An inertial accelerometer measures the vector $(\boldsymbol{a}-\boldsymbol{g})$ in its own coordinate system. In free fall, it should show zero. To convert the measured data to $\boldsymbol{a}$, as done by many apps [3,4], requires using also 3D rotational data and matrix operations, hidden from the user. Slinkies or spiral toys provide visual accelerometers [1,2,5]. The Equivalence Principle can also be used to argue for an operational definition of weight, $m(\boldsymbol{g}-\boldsymbol{a})$, rather than the more common gravitational definition, $m\boldsymbol{g}$ [6,7].

The Equivalence Principle is rarely mentioned in textbooks, whether for school or undergraduate physics, except possibly in connection with the theory of relativity. However, the "weak equivalence principle", involving objects with (rest) mass, is a fundamental principle, with consequences that often surprise students. Not only do objects fall together in vacuum, but also to a good approximation in air – "unless the air gets involved", as one 11-year old expressed it, when discussing experiments of dropping different pairs of objects [8]. In a chain flyer, an empty swing in front of you forms the same angle to the vertical [9,10]. On a playground, you can "twin swing" with an empty swing and compact balls of different size roll together down a slide [8,11]. Students can even discover that mass doesn't influences how fast something moves down a slide [12]. Physicists may be surprised about the behaviour of liquids in accelerated motion [13], also reflected in accelerometer data from swings [2,5]. The equivalence principle invites you to bring your body to physics class, as a resource for learning about Newton's laws.

Conclusions

Omitting the embodied experiences from physics discussions can leave students believing that the acceleration is zero, e.g., in the lowest point of a swing motion [5,14,15], or in the highest point when something is thrown up in the air [16], or when you bounce on a trampoline [17-19]. On the other hand, when acceleration is introduced through Newton's second law, ***a***=***F***/*m*, rather than through mathematics, it can be accessible long before students learn about derivatives [1,2]. There is no need to restrict discussions to one-dimensional motion – although in amusement parks, or on a trampoline, even 1-D motion can be exciting [20]!

References

[1] A.-M. Mårtensson-Pendrill, *Physics for the whole body in playgrounds and amusement parks*, AIP Publishing, 2021.
[2] S. Bagge and A.-M. Pendrill, Classical Physics Experiments in the Amusement Park, *Physics Education* **37** (2002) 507.
[3] R.E. Vieyra and C. Vieyra, Analyzing forces on amusement park rides with mobile devices, *The Physics Teacher* **52** (2014) 149.
[4] S. Staacks, S. Hütz, H. Heinke and C. Stampfer. Advanced tools for smartphone-based experiments: phyphox, *Physics Education* **53** (2018) 045009.
[5] A.-M. Mårtensson-Pendrill, Serious physics in a playground swing - with toys, your own body, and a smartphone, *The Physics Teacher* **61** (2023) 355–359.
[6] R. Taibu, D. Rudge and David Schuster. Textbook presentations of weight: Conceptual difficulties and language ambiguities. *Phys. Rev. ST Phys. Educ. Res.* **11** (2015) 010117.
[7] H. Stein, I. Galili, and Y. Schur. Teaching a new conceptual framework of weight and gravitation in middle school, *J. Res. Science Teaching* **52** (2015) 1234–1268.
[8] A.-M. Pendrill *et al*, The equivalence principle comes to school – falling objects and other middle school investigations, *Physics Education* **49** (2014) 648.
[9] A.-M. Pendrill, Rotating swings—a theme with variations, *Phys. Educ.* **51** (2015) 015014.
[10] J. P. Schilder and A.-M. Pendrill, The Coriolis effect and coupled oscillations in a rotating swings amusement ride, European Journal of Physics, **45** (2024) 025002.
[11] A.-M. Pendrill, Balls rolling down a playground slide: What factors influence their motion? *Physics Education*, **56** (2021) 015005.
[12] A.-M. Pendrill *et al*, Motion on an inclined plane and the nature of science, *Physics Education* **49** (2014) 180.
[13] C.-O. Fägerlind and A.-M. Pendrill, Liquid in accelerated motion, *Physics Education* **50** (2015) 648.
[14] C. Schwarz, The not so simple pendulum, *The Physics Teacher* **33** (1995) 225–228.
[15] A.-M. Pendrill, M. Eriksson, U. Eriksson, K. Svensson, L. Ouattara, Students making sense of motion in a vertical roller coaster loop, *Physics Education* **54** (2019) 065017.
[16] B. Gregorcic and A.-M. Pendrill, ChatGPT and the frustrated Socrates, *Physics Education* **58** (2023) 035021.
[17] A.-M. Pendrill and D. Eager, Free fall and harmonic oscillations – analysing trampoline jumps, *Physics Education* **50** (2015) 64–70.
[18] D. Eager, A.-M. Pendrill and N. Reistad, Beyond velocity and acceleration: jerk, snap and higher derivatives, *Eur. J. Phys.* **37** (2016) 65–8.
[19] A.-M. Pendrill and L. Ouattara, Force, acceleration and velocity during trampoline jumps—a challenging assignment, *Physics Education* **52** (2017) 065021.
[20] A.-M. Pendrill, Smartphones and Newton's first law in escalators and roller coasters, *Physics Education* **55** (2020) 035016.