Physics in your Pocket: Doing Experiments and Learning with your Smartphone

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Abstract

Current smartphones are powerful calculating devices that include a rich set of built-in sensors, which can be used to measure different physical quantities. These capabilities, and the fact that students usually have their smartphones within reach, facilitate the use of mobile devices to teach physics by using smartphones as measurement tools. Experiments that are easy to do and to understand must be designed to facilitate the students' use of smartphones either in laboratory experiments or in their everyday activities. In this work, we show two examples of such experiments using applications developed by our group. A second part of the Instructor's work must be to determine if the use of smartphones improves students' learning and motivation. Some preliminary results of our work with students show that engagement and motivation are improved when the students use their smartphones to learn. Our results on the effects on students' learning are not yet conclusive.

1 Introduction

In recent years, the use of mobile devices in education has increased enormously. In many areas, smartphones are used as knowledge facilitators to ease communication among students or between students and teachers, or to follow or assess the students' progress. For physics students, however, mobile devices have also become useful tools in experimental physics thanks to their rich set of built-in sensors (Kundt & Vogt, 2013). These sensors allow students to use their smartphones as measuring devices in laboratory experiments or during many everyday activities, where the students can strengthen their education by observing nature and contrasting their knowledge or beliefs with their own experimental results.

The use of smartphones as measurement devices in physics experiments with students requires careful attention to ensure positive learning outcomes. Some issues that must be considered include the reliability and accuracy of the smartphones' sensors as well as their adequacy to the experiment in which they will be used. In addition, the precision and accuracy of the applications used to access the sensors data are essential to obtain results that have physical meaning and do not confuse the students (González, González, Martín, Llamas, Martínez, Vegas, Herguedas, & Hernández, 2015). Teachers must also be careful about designing and implementing learning experiments that can be done with smartphones allowing the students to observe the physical phenomena without technical or theoretical difficulties. Finally, the influence of these experiments on different students' education must be carefully analyzed and gains in knowledge, motivation and engagement assessed.

Many recent works have described physics experiments covering many branches of Physics that can be performed using smartphones as experimental tools. Citing only a few of the most representative and interesting published works we have papers on acoustics (Kundt, & Vogt, 2013b; Parolin, & Pezzi, 2013, González, & González, 2016), astrophysics (Whiteson, Mulhearn, Shimmin, Brodie, & Burns, 2014), atmospheric physics (Monteiro, Vogt, Stari, Cabeza, & Marti), atomic physics (Gröber, Molz, & Kuhn, 2014; Kuhn, Molz, Gröber, & Frübis, 2014), magnetism (Silva, 2012), mechanics (Kuhn, & Vogt 2012b; Monteiro, Cabeza, & Martí, 2014; Vogt, & Kuhn, 2014; Monteiro, Cabeza, Marti, Vogt, & Kuhn, 2014, Patrinopoulos, & Kefalis, 2015; Monteiro, Stari, Cabeza, & Marti, 2015) and optics (Kuhn, & Vogt, 2012a; Yu, Tan, & Cunningham, 2014).

The use of smartphones as measuring devices in the teaching laboratories also permits the substitution of more expensive laboratory devices by smartphones, either by using their internal sensors (Castro-Palacio, Velázquez-Abad, Giménez, & Monsoriu, 2013; Kuhn, & Vogt, 2013b; Sans, Pereira, Gomez-Tejedor, & Monsoriu 2013; Vogt, & Kuhn, 2012) or by using simple and cheap electronics connected to the smartphones' ports (Forinash, & Wisman, 2012a; Forinash, & Wisman, 2012b; Forinash, & Wisman, 2015). These 'low-cost' laboratories would benefit institutions with large numbers of students and small budgets (González, da Silva, Cañedo, Huete, Martínez, Esteban, Manso, Rochadel, & González 2015), but are also an opportunity to design and implement new engaging curricula (Zavrel, & Sharpsteen, 2015).

As a consequence of this expansion of works on physics experiments performed with smartphones, some teachers have begun to wonder about the effects of using smartphones in physics education (Marciel, 2015). One very interesting study that is based on the theoretical framework of context based learning considers the effects of using smartphones on physics students' motivation (Kuhn & Müller, 2015) and shows that the connection of the experimental tool, the smartphones, and tablets, to the students' everyday life has a positive influence on students' motivation. In addition, other recent studies have reported positive outcomes of using smartphones in learning and motivation with temporal stability both for secondary school students (Kuhn & Vogt, 2015) and for university students (Klein, Kuhn, Müller & Gröber, 2015).

2 Doing experiments with smartphones

In this section, we describe some simple experiments that can be done using smartphones. In these experiments, we have used two free Android applications developed by our group: AudiA and Sensor Mobile that can be downloaded from the Google app store[1]. Audia (Cañedo, 2014; González, González, Martín, Llamas, Martinez, Vegas, Herguedas & Hernández, 2015) is focused on acoustics measurements and also describes different acoustic phenomena that can be studied with it. This application allows the calibration of the smartphone so that measurements done using different smartphones can be compared. Sensor Mobile (Huete, Esteban, Skouri, da Silva, González, Goudjami, Rochadel, & González, 2015) allows nearly simultaneous access to different sensors of the smartphone, thus recording measurements of different physical quantities in the same experiment.

2.1 Studying properties of materials with the smartphone

The authors Schwarz, Vogt, and Kuhn (2013) propose a method of obtaining the acceleration of gravity, g, by measuring the differences in time of several consecutive bounces. The method assumes that the air drag is negligible and that the loss of mechanical energy is the same in each bounce. As an intermediate step in their calculations, the authors obtain the coefficient of restitution of the ball, k, which establishes the ratio of kinetic energies after and before the bounce. This is later used to calculate g, knowing the initial height of the ball.

[1]

Audia : https://play.google.com/store/apps/details?id=es.uva.audia
Sensor Mobile : https://play.google.com/store/apps/details?id=com.sensor.mobile
These pages were last visited on 21 December 2015.

However, here we propose an alternative to this work and focus on the calculation of the coefficient as the final goal of the experiment. In this way, we can, for example, study the dependence of the coefficient of restitution of different materials with temperature and then apply the smartphone to simple material science experiments.

$$k = \frac{E_{k,a}}{E_{k,b}} = \frac{v_{0,a}^2}{v_{0,b}^2} = \frac{h_a}{h_b} = \frac{\Delta t_a}{\Delta t_b}$$

In this experiment, balls of different cheap and easily purchased materials can be used, so that the students can perform the experiment, or part of it, at home. For example, results shown here correspond to different quality golf and table tennis balls as well as a foam ball. In order to measure the effect of temperature, the balls can be submerged in liquids at different temperatures or kept in the freezer. In this experiment, we used liquid N_2 for the lowest temperature, a freezer for temperatures below 273 K and water for temperatures between water freezing and boiling points. For safety reasons, students carrying out the experiment unsupervised should be limited to a safe range of temperatures using only water and a freezer.

Once the calculations of k for different balls and temperatures are done, the students can visualize the different behaviors of the materials, as has been done in Figure 1. In that figure, results for four different balls are compared: a golf ball (golf), a good quality and a poor quality table tennis balls (ttgq and ttpq) and a foam ball (fb). For each ball, two calculations are shown to illustrate the results obtained: in one calculation, the coefficient of restitution was calculated using the ratio of times of the second and first bounces and in the other the ratio of times of the third and second bounces were used. Both calculations were used to analyze the assumptions of Schwarz, Vogt, and Kuhn (2013). As can be seen in that figure, golf data end at about 250 K. At lower temperatures, due to the different behavior of the materials of the ball layers, the ball outer layers tear apart.

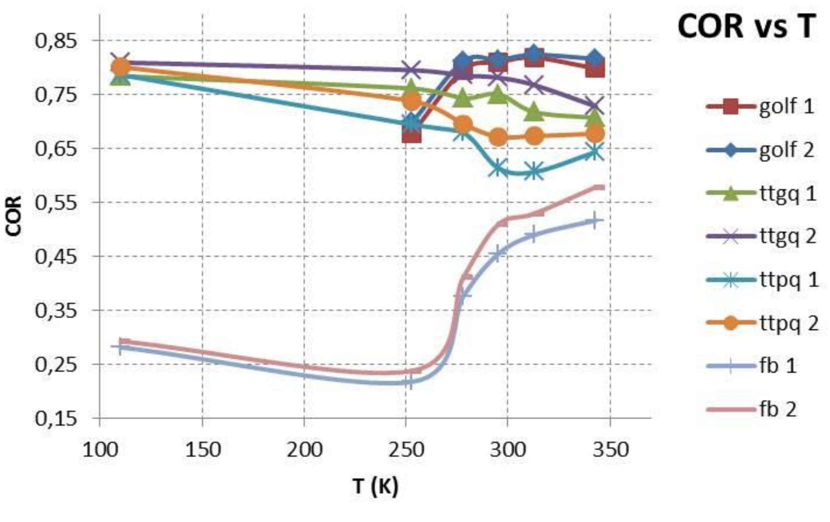

Fig. 1. Dependence of the coefficient of restitution of balls of different materials versus temperature. Two different quality table tennis (ttgq and ttpq), a golf ball (golf) and a foam ball (fb) have been used in the experiment. Results labeled as '1' in the figure correspond to the calculation of the coefficient of restitution using the ratio of times between the second and first bounces, while those labeled as '2' correspond to the calculation using the ratio between the third and second bounces times.

2.2 *Smartphone physics in everyday life*

Different studies have explored the use of smartphones in physics experiments during student activities outside the laboratory. Some of these works have focused on the rich physics that can be observed in amusement (Pendrill, & Rohlén, 2011; Pendrill, 2013; Vieyra, & Vieyra, 2014; Pendrill 2015) or water parks (Cabeza, Rubido, & Martí, 2014). Unfortunately, however, for most student's excursions to amusement parks cannot be considered as *every day* activities. Hence, other works have shown examples of experiments that can be done in more usual situations, such as in an elevator (Kuhn, Vogt, & Müller, 2014), in a merry-go-round (Monteiro, Cabeza, Marti, Vogt, & Kuhn, 2014) or in a car or bicycle ride (González, da Silva, Cañedo, Huete, Martínez, Esteban, Manso, Rochadel, & González, 2015). Here we show measurements taken in a flight take off as an example halfway between the excitement of an amusement park and the reliability of transportation. Figure 2 shows an example of simultaneous measurements of four magnitudes: acceleration, speed, traveled distance and magnetic field, using the Sensor Mobile app while the plane accelerates along the runaway and takes off. Off course, security regulations must be followed and the smartphone must be kept in flight mode during this time, however this restriction does not impede measurement with the smartphone's sensors.

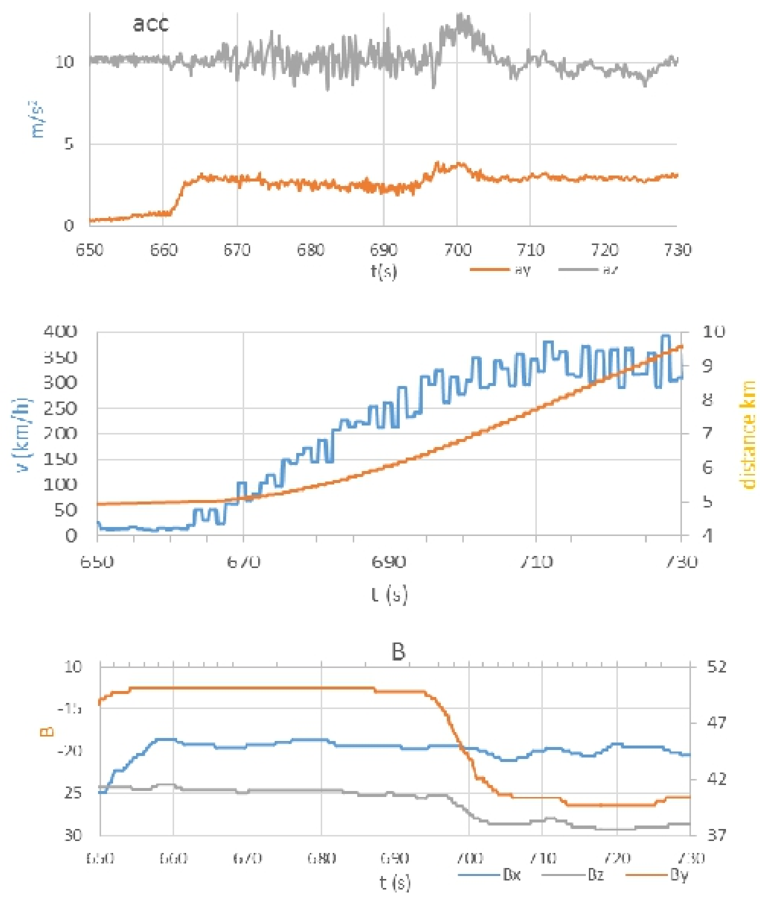

Fig. 2. Simultaneous measurement of acceleration, speed, distance traveled and magnetic field in a plane during take-off, recorded using a Samsung S4 smartphone with the application Sensor Mobile. Students can use measurements like these to understand relationships between different magnitudes and to explain physical phenomena, such as the plane movement along the runaway depicted here.

Simultaneous measurements allow the students to analyze the relationships between different quantities, for example by comparing the measured speed and traveled distances with those calculated by integration, even using a simple approximate method such as the trapezoidal rule with a spreadsheet, from the recorded acceleration. These measurements also allow the students to analyze data and understand the phenomenon from the graphs, explaining, for example, how the acceleration components change along the runaway and in the moment of take off, or the change in the magnetic field components due to the plane pitch at take off.

3 Some works with students

The second part of our research on the use of smartphones in physics education is focused on the analysis of how these tools affect students' progress and motivation. For such a study, learning analytics involving enough students at different levels, capacities and interests are required. Until now, we have done only preliminary works with university and high school students.

The work with university students consisted of supplying the students with mobile apps to complement their physics training. The students who used those applications were surveyed and their grades and engagement compared with those of the non-participants (González, González, Llamas, Martín, Vegas, Martínez, Hernández, & Herguedas 2014). From the survey results, we observed that students saw the use of smartphones as a positive complement to their curriculum. From the analysis of the influence on their grades and motivation, we observed that the use of smartphones increased their interest and engagement, reducing dropouts.

On the other hand, for our preliminary work with high school students we followed a different structure. A few students from two different high schools participated in this work. At the laboratory, they learned how to use the smartphones in simple physics experiments and how to analyze the sensors' data. Then, we propose for them to figure out experiments that could be done 'at home' or during everyday activities. Some of the experiments designed by these students consisted of measuring acceleration and speed in public transport, measuring the resonant sound frequency for different pipes and calculating the speed of sound in air. Other experiments involved measuring friction coefficients between different materials by using inclined planes, or checking the relationship between angular velocity, radius and centripetal acceleration in a carousel (González, González, Martín, Santos, del Pozo, Díez, Prieto, Martínez, Aznar, & de los Mozos 2015). Most of these high school students conceived, performed and analyzed at least two different experiments. Based on this as well as the students' feedback during our interviews with them, our conclusions are that using these devices increases students' interest in experimenting and learning physics, while improving their conceptual understanding. Nevertheless, one must take into account the preliminary character of the experiment, the low population of students involved in it and the qualitative character of the results.

4 Conclusions

The rich capabilities of current smartphones allows for their usage in many physics experiments in the laboratory or outside it. This opens up the possibility of reducing the costs of traditional laboratories by redesigning classical experiments to use smartphones instead of more expensive traditional laboratory material, and even allows students to bring their own devices, which can be very useful under conditions of low budget and large class sizes. Smartphones also allow students to observe and measure many phenomena by themselves. From our work with students, we have noticed that this activity increases their autonomous work and improves their motivation and engagement, reducing dropouts. In this sense, the use of mobile devices opens up the possibility of using learning techniques in which the students play a much more active role. To complete this work, a study on the influence on student's development is required. For that, it will be necessary to analyze academic results of students of different levels and characteristics.

Acknowledgements

The authors thank the University of Valladolid for its support to this work under grants PID2015_128 and PID2015_129.

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