Doing Physics Experiments and Learning with Smartphones

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ABSTRACT
Physics is a subject that for a complete teaching and learning requires both theoretical discussions and practical experimentation. In this work we describe how mobile applications can turn smartphones into versatile measurement devices for broad fields of physics. Different physics experiments performed using our own developed applications, both in the teaching laboratory and profiting from everyday activities, are described. The use of smartphones' applications opens the possibility of developing low-cost laboratories as well as international teaching collaborations.

Categories and Subject Descriptors
K.3.1 [**Computers and Education**]: Computer uses in Education – *Computer-assisted instruction (CAI), Distance learning*

General Terms
Measurement, Experimentation, Human Factors,

Keywords
mLearning, Physics, Experiment, Teaching/Learning strategies, smartphones, sensors, applications, Android

1. INTRODUCTION

Technology can play an important role in the way in which we learn and teach. Perhaps more importantly, technology can also play a fundamental role in easing the diffusion of knowledge and culture beyond schools or universities [1]. Along these last years perhaps the two ICT based learning techniques with a highest growth have been the massive open online courses (MOOCS) [2] and the so called mobile learning (mLearning) [3,4]. Among their benefits, these two technologies ease the access to knowledge of less favored communities and empower the students to build their own learning environments [5].

In this work we describe the use of mobile devices as probes in experiments of physics. For this purpose our group develops mobile applications to access the sensors included in current smartphones and tablets. In section 2, we will discuss the use of mobile devices in teaching laboratories as a way to reduce expenses by developing low-cost laboratories. In section 3, the use of mobile devices to measure different physical quantities in everyday activities, as well as its utility as a way of facilitating physics learning, will be discussed.

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2. SMARTPHONES APPS FOR A LOW COST LABORATORY

Many measurement devices designed to be used in a physics teaching laboratory reach cost levels that, for many laboratories, are unfordable. This may be true even for devices designed for fundamental physics experiments. Furthermore, even for those who can afford to buy those devices, in many cases, budget limitations impede them to have redundant devices to solve (usual) sudden failures that can happen in a teaching laboratory when, along a term, large numbers of students work with the same devices.

In some cases, a solution to these problems has been implemented by using remote laboratories [6-8] that allow the students to access experiments through the Internet. In other cases, teachers figure out and build their own experiments and arrange so called *low-cost* laboratories [9-13]. A third solution, since the advent of the Internet was, of course, the development of virtual (simulated) experiments and laboratories [14] that reproduce, using a computer program and graphics, the behavior of an experiment. The difference between this last solution and the two above is evident: while in the two first the students face real devices behavior with all their difficulties, the last one is only a mimic of the real world in the screen of a computer showing the expected result of the physical laws but not the difficulty inherent to real experimentation.

Nowadays current mobile devices open a new way thanks to their affordable electronics and built-in sensors. In fact, the possibility of using smartphones or tablets in physics experiments goes quite beyond remote laboratories and even classic teaching laboratories reach, as mobile devices allow the students to think and design their own arrangements and experiments. Students can use their smartphones and tablets in a variety of ways to perform experiments on different branches of physics [15-20]. In many cases, besides, data from the mobile devices' sensors are easily accessible through free applications that can be downloaded from the apps stores, what eases anyone, independently of his/her programming skills, to use those devices for measuring. Nevertheless, as teachers, we must advise that sometimes those free apps were not designed or implemented as learning tools, and even in some cases their results are marred by lack of accuracy either in the recorded data or in how data are presented [21]. These are important issues if a teacher wants to use the mobile device to do measurements, but it is more important yet if it is a students who uses that device to measure and learn.

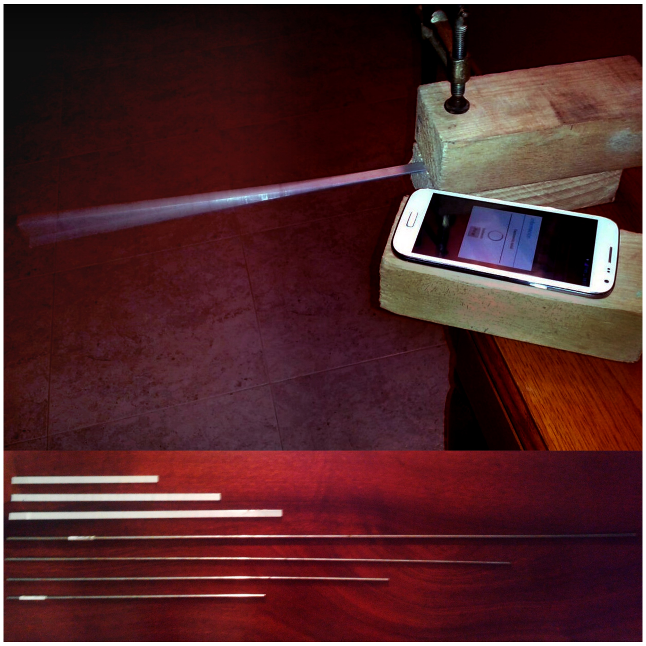


Figure 1. Top: Experimental arrangement for the measurement of vibrations in a metallic rod using the smartphone. Bottom: Metallic rods of different lengths, sections and composition used in the measurements and in the comparison with the analytical calculations.

These are reasons why some groups of teachers have been recently started developing apps specially intended to be use in physical measurements by students [22-24]. One of these applications, Audia [22] that even allows calibration of the smartphone before using it for measuring, can easily turn the smartphone in a versatile device for different acoustic measurements. In this way the smartphone can substitute recording systems, sound analyzers and other devices in the laboratory. One example of the use of this app in an experiment is depicted in Figure 1 top. In the example shown in that figure, the student carried out the experiment at home, what can also be understood as a proof of concept of a Bring Your Own Device (BYOD) [25-26] experiment in the laboratory, if the students use their own smartphones as measurement devices in the teaching laboratory. The bottom part of Figure 1 shows different rods of steel or aluminum used for the measurements of this experiment.

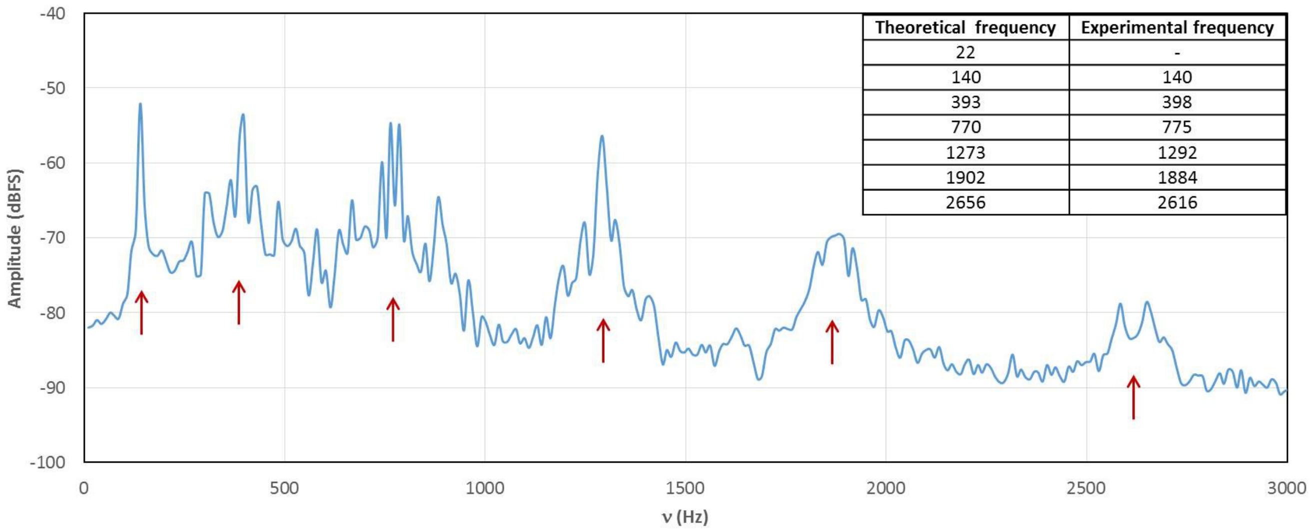
In this way, by using a simple arrangement and the smartphone, the students can do a simple experiment to analyze how oscillating frequency and its overtones depends on the material and geometry of the rod. Figure 2 shows some results of such an experiment: the oscillating frequencies calculated after the smartphone did a FFT of the sound recorded in the experiment. All this process, sound recording an analysis, was performed using the smartphone and the application Audia. As can be seen in this figure, the vibration frequencies can be easily identified within a range between 100 and 4000 Hz. The table inserted in this figure shows the good agreement between the measurements with the smartphone and the theoretical values [27], which is a proof of the reliability of both the smartphone and the app for scientific measurements.

In Figure 3, the theoretical values of the overtones for rods of different lengths are compared with the experimental results obtained with the mobile application. As can be seen in that figure, the application is accurate enough along a large range of frequencies, which is very remarkable considering that these results imply both the sound recording and its analysis by the application. Another advantage of using our own applications is that we know well their range of applicability. For instance Audia, due to the sensitivity of the microphone, can not detect correctly the fundamental harmonic, which can be, however, be solved by using an external microphone.

3. USING SMARTPHONES TO CARRY OUT PHYSIS EXPERIMENTS ALONG EVERYDAY ACTIVITIES

While using the smartphones to replace some expensive measurement devices in the laboratory has many advantages, the possibility of doing physical observations and measurements along everyday activities facilitates learning in a different way. The students observe nature directly, use their own devices to measure different magnitudes, confront their experimental results and accuracy with their theoretical concepts, and learn how what they learn in the classroom affects their own lives. And all this can take place anytime and anywhere, so that the use of smartphones and tablets ease physics learning by transforming the whole world in a classroom and laboratory where the students can learn [28].

SensorMobile [23,29], a multilingual app implemented by our group in order to be used as a help for students learning, allows us to access simultaneously to different sensors of the smartphone and to record measurements of different quantities, as acceleration, magnetic field, proximity and light and sound intensity, which can be analyzed jointly. Besides, it also allows GPS positioning so that not only the measurements can be geo tagged, but also positions and velocities can be obtained from the GPS data. Then, this application allows the students to perform many different experiments in their daily activities.



Theoretical frequency	Experimental frequency
22	-
140	140
393	398
770	775
1273	1292
1902	1884
2656	2616

Figure 2. Vibration frequencies recorded by the application used in an experiment with a 355 mm long flat rot of steel. The inserted table shows a comparison of the theoretical frequencies and the recorded values, marked with arrows in the figure.

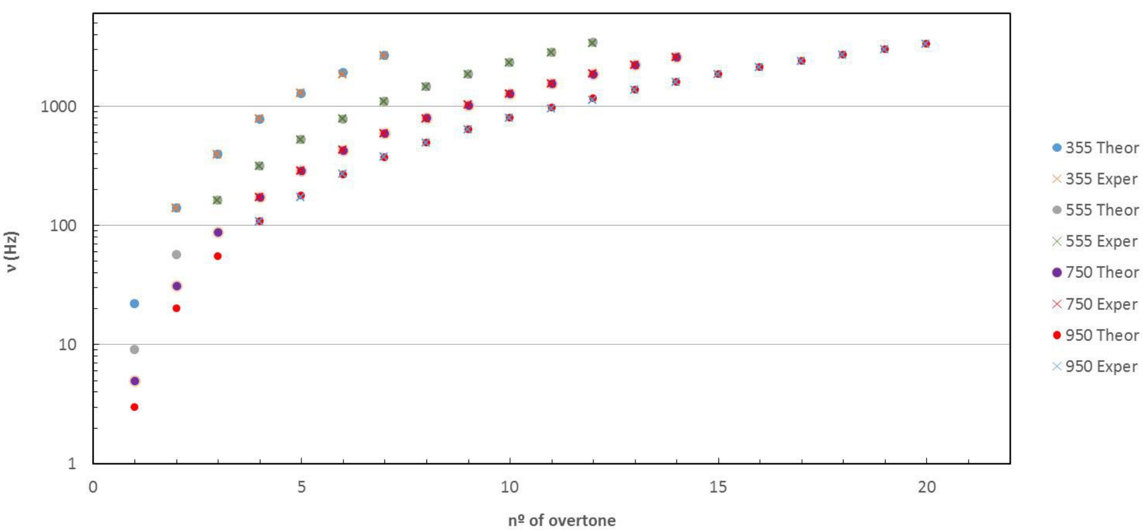


Figure 3. Comparison between the application measurements and theoretical values of frequencies and overtones for vibrating rods of different lengths The frequency axis is in a logarithmic scale for a better visualization of the data.

Using the SensorMobile app, students can use the data from the accelerometer and the gyroscope to study the movement whilst they commute from home to school, and then analyze the results using GPS data and a map to see the correspondence of their measurements with turns, straight accelerations, etc. They can also measure magnetic fields when they approach wires or transformers. Even at home, they can use the magnetometer to measure the magnetic fields along home wiring when they turn on or off ovens or washing machines. Other home experiences could consists of measuring how sound is absorbed by different materials like the doors wood or the brick or concrete walls, or how some loudspeakers can distort sound depending on the sound intensity. Also the light or sound intensity sensors can be used at home to analyze and check the inverse square law. Outside home, the students can use the gyroscope and accelerometer in the playground to analyze the movement in different swings or sliders.

As an example of an experiment using multiple sensors simultaneously we show here results obtained using SensorMobile in a work to home short trip. In this experiment the accelerometer, gyroscope, light intensity sensor, magnetometer and GPS were used simultaneously. The repeatability and noise of the measurements were checked by comparing the results obtained in different trips. Using the data recorded by the different sensors together with the analysis of the trajectory from the GPS data, the students can study different concepts explained in a fundamental physics course, as speed, acceleration, magnetic field, etc. and relate them to their personal experiences. As an example of one of these measurements Figures 4 to 8 show results of one of these experiments using everyday activities. Figure 4 shows the trajectory followed in the experiment from the GPS data recorded by the application and the axis for the smartphone measurements.

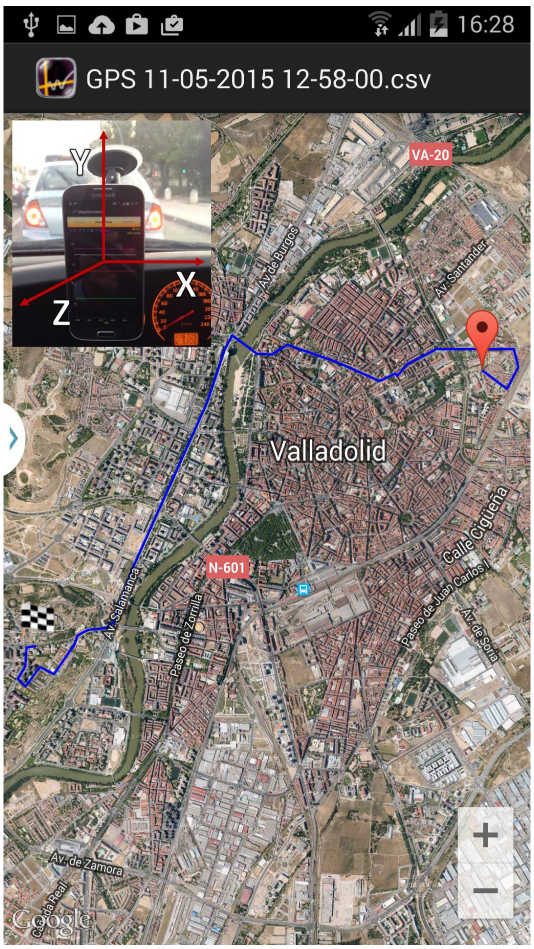


Figure 4. Trajectory followed along a daily trip from home to university used to record data using the smartphone sensors.

An important aspect of physics experimentation is repeatability. This implies that along different runs of the same experiment similar results should be obtained, or that different experimenters should record similar data along the same experiment. Figure 5 shows two series of data obtained in this home to work ride experiment along two different days. As can be seen there, the data agree well in spite of the experimental noise of such an experiment, probing the reliability of the smartphone sensors for these measurements. For clarity only the magnetic field data recorded in the two experiments is represented in Figure 5. In order to enhance the comparison, the two data sets are represented versus the traveled distance, and not the traveled time as this can be affected by conditions, as may be the state of the traffic, that can't be uncontrolled by the experimentalist.

An example of the results recorded in different sensors along the experiment is displayed in Figure 6. In this figure the data from two components of the accelerometer (X and Z), the Y component of the gyroscope and the instantaneous value of the speed, obtained from the GPS data, are shown together. See figure 4 for an illustration of the smartphone axis. Analyzing figures like this the students can observe directly the relationship between the acceleration and the change in speed or in direction of the movement. In this experiment the smartphone was placed with its accelerometer Z component, acc z, along the direction of movement, so that while the Z component of the accelerometer is null the speed obtained from the GPS data is constant, but when acc z is different from 0 the speed changes, depending its change of the value and of the sign of acc z. On the other hand, the X component of the accelerometer, acc x, corresponds to the centripetal acceleration that appears when the car turns. Then, the values of acc x are correlated with the data from the gyroscope component y, that gives the rotation of the car along that axis and the students can study the relationship between centripetal acceleration, acc x, and the angular speed that can calculate from the gyroscope. All these are data that can illustrate well, both from a qualitative and from a quantitative point of view, many physical concepts of a basic physics course and show how the students can learn physics simply by using apps like the one described here in many usual activities. Of course, in order to obtain better learning results it would be advisable that the students use for their analysis figures a little less complex than the shown here, with shorter periods of time or comparing only results from two different sensors each time. Following the comment above, Figure 7 shows more clearly another interesting result useful for learning basic concepts of kinematics. In this figure we have plotted only the dependence of the speed and distance along time obtained by the SensorMobile application from the measured GPS data. From similar figures the students can easily understand the relationship between both concepts, both from a physical and from a mathematical point of view. For example, the students can see that the position remains constant, or nearly constant considering the GPS accuracy, when the speed has a null value, as is seen in the square labeled as A in figure 7. Also, the students can analyze quantitatively the rate of change of the position and how it increases with increasing speed, as in the square B in that figure. In that square the rate of change of the position vs time curve has been averaged with a straight line of constant slope to reduce the experimental noise. The students can then compare that averaged value with the average value of the speed in the same time interval for a quantitative analysis in order to deduce the mathematical relationship between speed and position. In order to make easier comparisons, the students can limit their analysis to short intervals of time for which the speed is nearly constant.

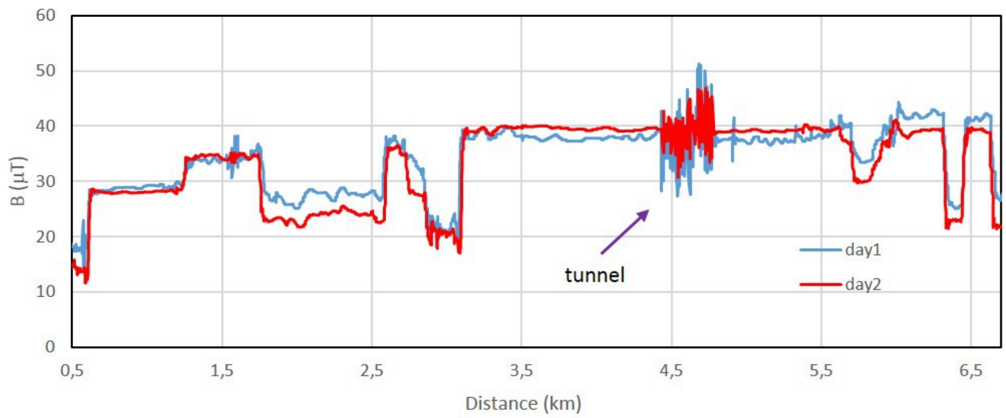


Figure 5. Comparison of the magnetic field recorded using SensorMobile along the same trip in two different days.

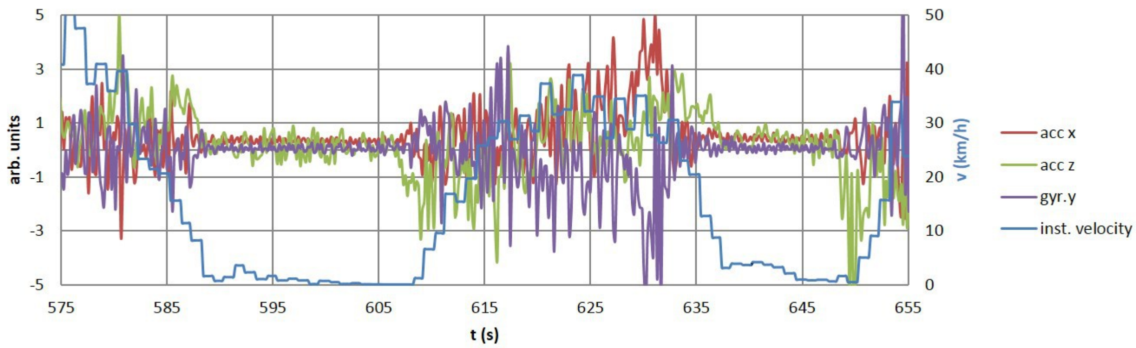


Figure 6. Results obtained using different sensors simultaneously with the SensorMobile app. Here, the results of two components of the accelerometer, X and Z, one component of the gyroscope, Y, and the speed obtained from the GPS are displayed together.

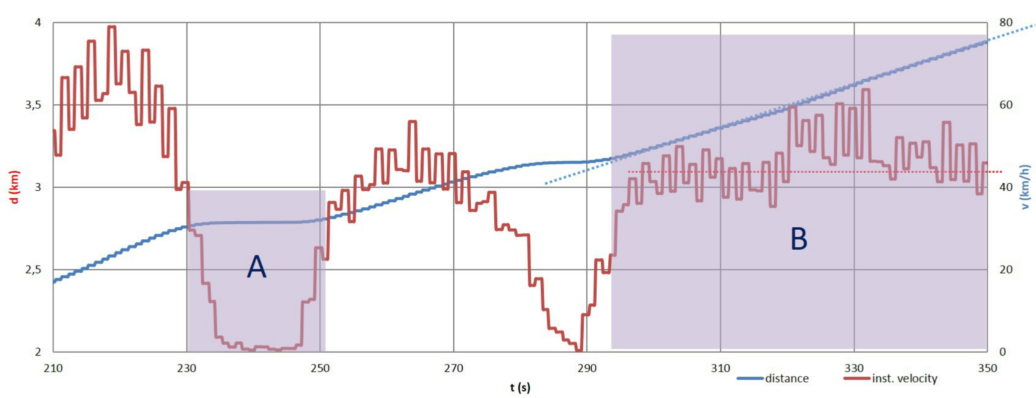


Figure 7. From the GPS data students can analyze the speed and distance along time and compare their relationship.

Finally Figure 8 shows the superposition of the results recorded with the accelerometer over the trajectory coordinates (latitude and longitude) obtained with the GPS. By using these combined graphs students can visualize the dependence of acceleration or velocity on the trajectory characteristics, as slopes, turns, etc.

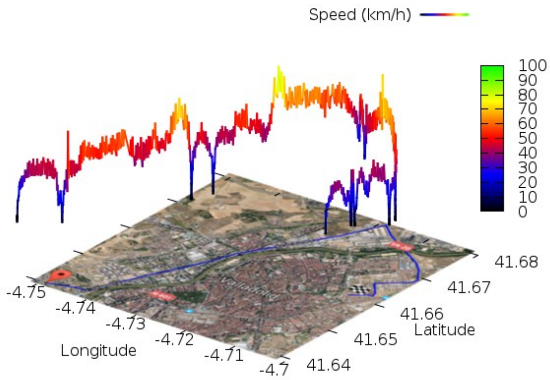


Figure 8. Correlation between the trajectory, using the latitude and longitude obtained with the GPS as in Figure 4, and the speed of the vehicle. The students can compare their measurements of different magnitudes with the trajectory in order to better understand, dependences, changes or singular points.

4. CONCLUSIONS

Mobile learning opens new possibilities for teaching and learning, facilitating the access to knowledge resources anytime and anywhere. At the same time, it eases the access to knowledge of less favored populations. But, beyond the role of knowledge facilitators, mobile devices can also play an active role in physics teaching and learning. We have shown in this work how mobile sensors can be used to measure a variety of physical magnitudes. For these measurements to have a positive impact in students' learning, it's crucial that at least some characteristics of the mobile applications used to access the devices sensors are designed or checked by teachers. Between these characteristics we must cite the accuracy of the recorded results, the correct use of magnitudes names and units or the correct mathematical treatment of the recorded data. In order to correct some mistakes or conceptual gaps found in some freely available apps, our group designs and implements learning apps to be used in physics measurements. Our experiments with the developed apps have shown their reliability in several fields of physics as well as their utility in both, the laboratory work, substituting more expensive experimental devices, and outside the laboratory, along many everyday activities of the students. Two of the more important consequences of this reliability are, then, the possibility of developing low cost laboratories by using smartphones and tablets instead of more expensive devices, and second, the capability of extending the learning environment beyond the walls of the classrooms or laboratories.

5. ACKNOWLEDGMENTS

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