Learning Physics Down a Slide: A Set of Experiments to Measure Reality Through Smartphone Sensors

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***Abstract*—During the last decade, the use of smartphones among teenagers in their daily life has grown significantly. Despite the efforts to use tablets in learning processes, these teenagers are often prompted to switch off their personal devices before entering a classroom. Moreover, most mobile learning applications do not take advantage of the device sensors (e.g., touchscreen, accelerometer, or gyroscope). In order to overcome this situation, we have developed Serious Physics, a free mobile app that allows using smartphones as measuring tools to conduct experiments on Physics.**

***Index Terms*—educational programs; educational technology; physics education; sensors;**

I. INTRODUCTION

There are literally thousands of mobile educational applications available in the app markets [1]. These apps offer new learning experiences, ranging from simple interactive books to complex Augmented Reality simulations [2]. In regard to learning Science, there are content-based apps such as interactive periodic tables of elements (e.g., Merck PTE HD) or exploration tools to navigate through all parts of a 3D model of the human body (e.g., 3D Anatomy), and problem-based apps, often designed with a challenge-solution approach (e.g. Mathway, Algebra Touch). Something similar happens with applications for learning Physics (e.g., Constant Table, Learn Physics). Moreover, most mobile learning apps do not take advantage of the device sensors to enable an experimental approach. For this reason, we decided to develop Serious Physics, an Android-based free mobile app to conduct experiments on Physics using the smartphone as a measuring tool.

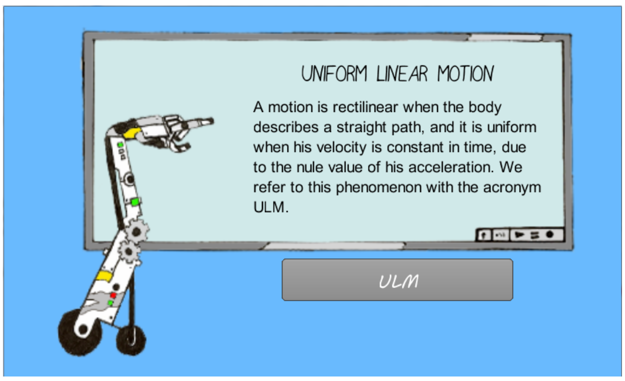

Figure 1. Serious Physics: Uniform Linear Motion explanation.

II. AIMS AND SCOPE

Our proposal addresses the improvement in the learning of Physics by 12 to 18 year-old students in the Basque Country (Spain). Therefore, Serious Physics provides theoretical and practical contents based on the curriculum designed by Dept. of Education of the Basque Government, and also a set of experiments that take advantage from the smartphone sensors to gather real measurements. Considering its scope, Serious Physics is freely available in English, Spanish and Basque, and relies on an extensible architecture that allows to design and build new experiments to cover other topics of the curriculum.

III. RELATED WORK

In addition to the commercial apps mentioned before, there are some previous research works that address the issue of adopting an experimental approach in the learning of Physics. Kuhn and Vogt noticed that the use of mobile phones as experimental tools has been a neglected topic in the field of educational research [3]. They focused their research on the mobile device as a mean of documentation, due to the possibilities that offer the microphone and the camera of the device. Surprisingly, Kuhn and Vogt did not cover the use of other sensors included in mobile devices. In that sense, it is particularly interesting how they propose an experiment to estimate the gravity using the microphone instead of the accelerometers of the smartphone as Peters proposed three years before [4].

Chevrier et al. developed a set of experiments within the iMecaProof project to help in the teaching of classical mechanics [5]. In this project, users are provided with an application with features divided in different levels of expertise (from 0 to 3) which include data gathered by the sensors of the mobile device to support theoretical explanations. SPARKvue is another project that allows to gather sensor data from a mobile device (and from external sensors too) [6].

Using a completely different approach, Gabriel and Backhaus combined the GPS sensors of the mobile devices with Google Maps to develop an application intended to support the teaching of Kinematics [7].

IV. SERIOUS PHYSICS

In addition to its theoretical and practical contents (see Fig. 1), Serious Physics enables the use of a mobile device to conduct several experiments on Kinematics. As can be seen in Table 1, there are many new scenarios where Serious Physics users can learn about Kinematics in an experimental way. The modular architecture of the software (based on free software libraries, such as LibGDX, OpenGL, or Box2D) allows covering other topics and scenarios on the top of it.

TABLE I.
EXPERIMENTS AND SCENARIOS

Concept	**Sensors**	**Scenario**
Uniform Linear Motion	Touch screen	Indoors, self-study
Uniformly Accelerated LinearMotion	Accelerometer Gyroscope Magnetometer	Indoors, free fall; outdoors, park with swings and slides
Circular Motion	Accelerometer Gyroscope	Outdoors, park with tire-swings and roundabouts

How students and teachers might use these features to improve their understanding of physics? Imagine a school scenario where: (a) students have mobile devices (e.g., *smartphones, tablets, phablets*) able to run Serious Physics; and (b) teachers are willing to go to a playground with them to perform a set of experiments. If that were the case, teachers might begin the explanation of Kinematics with a discussion session for groups or couples of the theoretical content offered by the application. Once the concepts involved have been assimilated, students could define a series of experiments to test them. In these experiments, students define the initial conditions and the expected results according to the underlying theoretical models, as well as the boundary cases that may lead to complications in the procedure. Not all of these experiments require visiting a playground, some of them can be conducted indoors without any problems. However, collating scientific experimentation with experiences as fun as going down a slide can be an incentive even for students not interested in Physics.

In order to get as close as possible to the scenario presented before, we conducted three experiments in which we try to prove empirically that they meet the underlying theoretical models.

A. Experiment 1: Uniform Linear Motion

Description. Through this experiment we want the student to understand the foundations of Newton's First Law of motion in a practical way. This law is often stated as *"An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force"*. To this end, the application captures the motion of a finger along a rectilinear path on the screen and then displays the speed of the finger. Students can then check whether the previous calculations correspond to those measured by the application or not.

Sensors. Current phones and tablets feature touchscreens that are able to detect multi-finger movements. We gather the speed of the finger from the touchscreen in pixels/s and then convert it to m/s.

Procedure. We conducted a series of eight measurements of the time and space covered by a finger sliding on the screen of a mobile device in order to have an estimate of the accuracy and precision of the measurement. Considering that the sliding finger travels 5 cm along the screen (i.e., three quarters of a regular screen) without any acceleration in approximately 0.1 s, students can use the well-known equation of Uniform Linear Motion (1) to predict the results of the tests:

$$v = \frac{s-s_0}{t}; v = \frac{0.05\,m - 0\,m}{0.1\,s}; v = 0{,}5\,m/s \quad (1)$$

Results. The speed values gathered during the eight attempts are shown in Table 2.

TABLE II.
UNIFORM LINEAR MOTION

Attempt	**Speed (m/s)**
1	0.43726072
2	0.7753074
3	0.48552343
4	0.5373729
5	0.48787132
6	0.43785048
7	0.56286395
8	0.6531293

As we can see, the results are compliant with the predicted value (M: 0.522, SD: 0.075).

Given the simplicity of this experiment, it might be autonomously conducted by students during class, at home as homework, or even during the trip to the playground. After that, students can compare the results with their predictions and with the results of their classmates. Another interesting approach is to conduct the experiment first and then try to figure out which factors are involved in the Uniform Linear Motion and which are the interactions between them. To facilitate this task, teachers can provide students with a list of possible factors and ask them to prove or discard their implication in Uniform Linear Motion.

B. Experiment 2: Uniformly Accelerated Linear Motion

Description. In the experiment of Uniformly Accelerated Linear Motion of Serious Physics, students can analyze both the movement of the mobile device in free fall (on a soft surface such as a pillow or a bed), as the downward movement of the mobile device along an inclined plane. We recommend starting with the first case because it is easier to understand and calculate since it does not require estimating the value of the acceleration. Instead, acceleration corresponds with the value of g (i.e., 9.8 m/s^2) in this case. In the second case, the value of the acceleration depends on the angle of the inclined plane and the friction coefficient of the surface on which slides the mobile device. Equation (2) is used to calculate the distance traveled. In the first case students can estimate it by simply replacing a with g, whereas in the second case it is necessary to calculate the acceleration using equation (3).

$$d = \frac{1}{2}at^2 \quad (2)$$

$$a = g(\sin\alpha - \mu\cos\alpha) \quad (3)$$

Sensors. Two different mobile sensors are used in this experiment. First, we estimate the angle of the plane using the magnetometer. Second, we log the acceleration changes in each axis via the accelerometer.

Procedure. We conducted a series of eight tests throwing the mobile device along a slide. In all these tests, Serious Physics recorded the time (detecting the beginning and end of the movement) and the acceleration in order to estimate the inclined plane angle (i.e., the slide), the distance traveled and the height from which it has been thrown. All tests have been performed on a slide with a height of 2 m and an inclination of 40 º.

TABLE III. UNIFORMLY ACCELERATED LINEAR MOTION

Attempt	Length (m)	Height (m)
1	3.22	2.06
2	2.91	1.86
3	3.65	2.336
4	3.34	2.13
5	3.50	2.24
6	2.98	1.90
7	3.25	2.08
8	3.09	1.97

Results. The results of these tests are shown in Table 3. As can be seen, there is some variability in them due to small differences in the execution of each test (Heigth, M: 2.072, SD: 0.163; Length, M: 3.243, SD: 0.252). Fig. 2 shows a screenshot of Serious Physics after performing one of these tests, providing estimates of the angle, distance and height.

C. *Experiment 3: Circular Motion*

Description. Students find the circular movement more difficult to understand, not only due to the trigonometry involved, but also because it is much more common to have first-hand experience of Uniform Linear Motion (e.g., using a conveyor belt at a constant speed on a airport) or Uniformly accelerated Linear Motion (e.g., traveling in a car that accelerates slowly on a straight stretch of road), rather that first-hand circular movements. Through this experiment provided by Serious Physics we intend to address this problem, providing first-hand experiences of circular movements that students can easily control.

Sensors. Gyroscopes are used to estimate the number of spins made by the mobile device.

Procedure. Analogously to previous experiments, we carried out a series of eight tests using the circular motion experiment of Serious Physics. The circular motion is defined by equation (4).

$$\omega = \frac{n2\pi}{t} \tag{4}$$

As long as it is necessary to know the value of the radius in this equation, it will be provided by the user of the application. As it happened in the experiment of Uniformly Accelerated Linear Motion, the user has to indicate the start of the experiment and then the application will start counting the time from the moment it detects movement (this time measuring procedure ends automatically when the mobile device stops completely). After completing a test, the application provides the angular velocity (ω) in

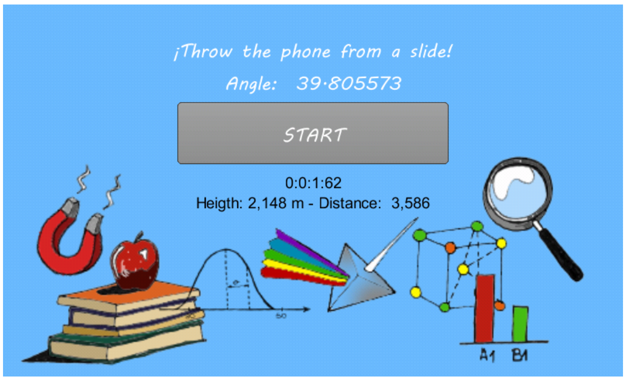

Figure 2. Serious Physics: Uniformly Accelerated Linear Motion experiment

rad/s, the speed ($v = \omega r$) m/s and the frequency of rotation ($f = \omega/2\pi$) in rpm (see Fig. 3).

Results. The results of the tests are shown in Table 4. In contrast to previous experiments, it makes no sense to analyze the stability of the measurements taken, because each test was conducted with a different number of revolutions. This approach, which can also be used in other experiments already mentioned, is interesting in order to improve the comprehension of circular motion by the students. It allows checking compliance of gathered results with the underlying theoretical model using different parameters and understanding the relations between them.

TABLE IV. CIRCULAR MOTION

Attempt	ω (rad/s)	v (m/s)	f (rpm)
1	9.08	2.724	86.70
2	11.15	3.345	106.52
3	12.74	3.822	121.71
4	8.13	2.439	77.94
5	8.98	2.694	85.79
6	9.65	2.895	92.19
7	10.88	3.264	103.94
8	9.2	2.760	87.89

V. DISCUSSION

Along the experiments described above, we have seen how mobile devices can be used for learning physics from a practical approach. Considering the popularization of mobile devices (more than 100 million smartphone owners in the U.S. in 2012 [8]), especially among students, it is not hard to imagine a near future in which science learning is facilitated by the use of sensors available on mobile devices.

Not only traditional pedagogies could take advantage from this approach. Newest proposals like the “flipped classroom” [10] in face-to-face education or Massive Open Online Courses (MOOCs [11]) and Small Private Online Courses (SPOCs [12]) could also benefit greatly from it. When a teacher decides to use a flipped classroom methodology, theoretical contents are individually attended by students as their homework, while class time is devoted to tutored practice. In this scope, Serious Physics can be used for both tasks. At home, to learn about the

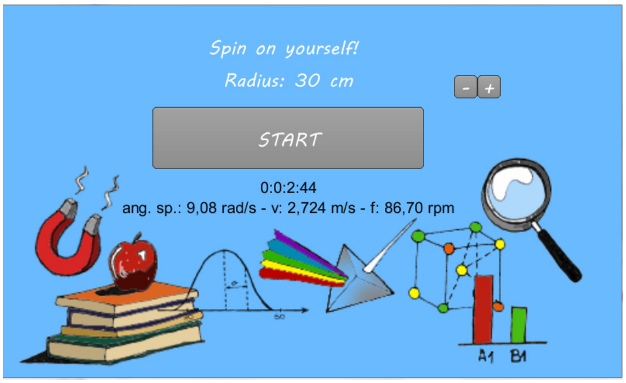

Figure 3. Serious Physics: Circular Motion experiment

theoretical concepts like other conventional mobile applications about Physics, but also in class during practical experimentation with examples like those discussed in the previous section. In regard to online learning, some of the recurring criticisms of this type of learning is its excessive emphasis on content distribution and the limited time devoted to practice. The approach proposed by Serious Physics could help to balance this inequity between theory and practice in these courses.

However, what we have shown in this article is only the beginning of a long road. Thanks to the modular architecture of Serious Physics, it is relatively easy to add new experiments to the application. These are some of the ideas for new experiments in which we are working:

Energy consumption experiment: In this experiment students will record a journey on foot or by any other means of transportation (e.g., bicycle, bus, car, train) using the mobile device's GPS and then the application will provide information about the speed average, accelerations, or the energy consumed in easily understandable terms (e.g., on this trip has been spent the energy equivalent to that provided by 6 kg. of french-fries eaten by a person).

Pressure waves experiment: In this experiment students will emit a sound wave via the speakers of the mobile device and subsequently capture how it resonates on a wall using the microphone. Serious Physics will then estimate the distance between the mobile device and the wall.

Electromagnetic waves experiment: In this experiment the students will be able to transmit information using the frequency variations of an electromagnetic wave, either visually (using the screen of the transmitter and the camera of the receiver) or via infrared waves.

Magnetic fields experiment: In this experiment students will understand the basics of magnetic fields using the magnetometer present in most mobile devices to provide the compass feature.

Moreover, we are open to suggestions, comments or collaborative projects that seek to benefit from the diverse and powerful set of sensors that incorporate today's mobile devices. Our ultimate goal is that teachers and students realize that they have an advanced laboratory in their pockets waiting to unleash its potential to facilitate science learning.

VI. CONCLUSIONS

Serious Physics represents another step towards the adoption of the smartphone as a learning tool. Not only as a mere content player, but also as a sensor-based mobile laboratory.

Although its functionality is still limited and there is a long way to go in improving and extending its features, we consider that Serious Physics faces a problem mentioned repeatedly by students once they complete their education process: What use are all the equations learned? When I shall have occasion to use them in real life? Memorizing an equation is used to solve an exercise correctly and, therefore, to pass exams. Discovering through experimentation is a completely different thing (i.e., infer what are the factors that affect a particular physical phenomenon and come to the underlying theoretical model with the help of a tutor). This results in a much more insightful, applicable and hard to forget learning.

REFERENCES

[1] Dickens, H., & Churches, A. (2011). Apps for Learning: 40 Best iPad/iPod Touch/iPhone Apps for High School Classrooms. The 21st Century Fluency Series. Corwin, A SAGE Publications Company. 2455 Teller Road, Thousand Oaks, CA 91320.

[2] Cobcroft, R. S., Towers, S. J., Smith, J. E., & Bruns, A. (2006). Mobile learning in review: Opportunities and challenges for learners, teachers, and institutions..

[3] Kuhn, J., Vogt, P. (2013). Applications and Examples of Experiments with Mobile Phones and Smartphones in Physics Lessons. Frontiers in Sensors (FS), Volume 1 Issue 4.

[4] Peters, R.D. (2010). Physics Education using a Smartphones Accelerometer.

[5] Chevrier, J., Madani, L., Ledenmat, S., Bsiesy, A. (2012). Teaching Classical Mechanics using Smartphones.

[6] SPARKvue. https://itunes.apple.com/de/app/sparkvue/id361907181

[7] Downhill and Projectile Launcher. http://smartphonephysics.com/freephysicsappsandroid.html

[8] Gabriel, P., Backhaus, U. (2013). Kinematics with the assistance of smartphones: Measuring data via GPS – Visualizing data with Google Maps.

[9] comScore, (2012). 2012 Mobile. Future in Focus. comScore, February 2012.

[10] Bergmann, J. (2012). Flip Your Classroom: Talk To Every Student In Every Class Every Day Author: Jonathan Bergmann, Aaron Sams, Publisher: Inte.

[11] Siemens, G., and Downes, S. (2008, 2009). Connectivism & connected knowledge: CCK08, CCK09. http://ltc.umanitoba.ca/connectivism

[12] Fox, A., & Patterson, D. (2013). What We've Learned from Teaching MOOCs. https://www.edx.org/blog, May 8, 2013.

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