Mobile Phones for Teaching Physics: Using Applications and Sensors

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ABSTRACT
This paper describes several experiments performed by our research group on physics to show the use of smartphones in teaching. We document our work on the development of apps for smartphones and on how to use sensor data acquired. As a final result, some interesting outcomes are obtained from the surveys conducted on the students about the use of these applications and their mLearning experience in general. These results show that the students are very interested in using smartphones as a complement to a more traditional learning. Finally, the influence of using the developed applications on students' grades and engagement was also analyzed. The results of this analysis prove that the use of smartphones highly improves students' engagement.

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, Laboratory, Engagement, Teaching/Learning strategies, smartphones, sensors

1. INTRODUCTION
In the recent years the use of computers in education has dramatically evolved from computer-assisted learning to web-based learning to mobile learning [1]. Mobile learning, mLearning, [2,3] has also risen the aim of a personalized, nearly ubiquitous and permanent learning for the new educational demands. These circumstances give the students the possibility to actively participate in the design of their own virtual learning environment. From a different point of view, students' interest in mobile technologies can be used as a powerful tool to reinforce their active participation in the classrooms [4], and to increase their interest in learning and their engagement [5].

Physics teachers can also take advantage of other characteristics of mobile devices in order to improve students' learning: the increasing capabilities of modern mobile devices, smartphones and tablets, as well as their set of built-in sensors, as accelerometer, gyroscope, magnetic sensor or light detector, permit to design low-cost real experiments. Indeed students and teachers can use them as measurement devices both in learning laboratories and in many daily activities, where they can apply what is learned in the classroom [6,7].

There is a general agreement that mLearning facilitates the access to education but, besides, some characteristics of mLearning can contribute to change the way in which we teach or learn. An important feature of mLearning is that one of its goals, different from those of a traditional transfer of knowledge from teacher to student, is to empower students to actively participate in the construction of their own learning [DELAPENA2007]. Also, mLearning can facilitate designs of real learning by targeting problems of interest to the learner [9], as well as ease lifelong learning by supporting learning that occurs during the many activities of everyday life [SHAR2005]. And considering the capabilities of mobile devices to ease communication between users, either directly or by using social networks, according to theories of new learning, mLearning can improve learning outcomes by including in a natural way communications withing the learning process [KYR2002]. As a conclusion, there is an important research that must be done to investigate how mLearning contributes to promote new learning [VALK2012]. In this sense, the analysis of the learning results obtained using mobile devices in different ways to teach or learn can be a useful method to answer that question.

In this paper we describe the work that our group is doing on the use of mobile devices to teach physics. On the one hand, some applications developed by our group together with different design issues will be explained in Section 2. On the other hand, some examples of the use of smartphones sensors to help learning will be discussed in Section 3. Finally, we have also surveyed the students in order to know their opinions on some of the applications developed by our group and on mLearning in general. The survey and its main results will be discussed in Section 4.

2. DEVELOPING LEARNING APPS

One of the researching lines of our group consists of developing mobile applications for teaching/learning physics and studying the effect of using those applications in the students' grades and engagement.

Several issues must be addressed when implementing mobile applications for teaching. One of those issues is how mLearning affects the way students learn when using small pieces of knowledge supplied by different, although complementary, applications. In [9] the author speaks about evolving notions of knowledge and learning due to the impact of the need to organize and work with small pieces of knowledge in mobile learning, together with the possible creation of individual ontologies as each learner navigates its own learning journey by using different applications, or following different learning paths with them. In fact, the limited size of learning oriented mobile applications and the necessary restriction of their contents to specific concepts or phenomena, so that more complex phenomena must be organized or distributed along different applications, has been the subject of different researches. For example, in [10] the authors described an experiment on the use of mLearning in a working domain in order to study the characteristics that mobile learning objects should fulfill to be useful when employed either in an exploratory learning or as small chunks of information. The authors of [10] concluded that the use of mobile devices in short periods of time recommends designing the applications so that they supply the learners with small pieces of information, what makes necessary to divide a subject into different independent parts [10]. This division of the contents into small pieces of information also allows the students to pause the learning with the mobile in a given time and re-start it easily anytime later. That necessary granularity of the content delivered through the mobile applications was also discussed in [11], where the author also stressed out the utility of mLearning complimenting existing formal courses, as we do with our applications.

Another issue that must be addressed is pointed out in [12]: “when learners' own phones are used, the minimal technical conditions need to be coordinated with the most effective pedagogical approach”. We have checked that in our case we have students with devices, from smartphones to tablets, with very different characteristics and capabilities. Then, when implementing a mobile application for the students, one must carefully consider the requirements of the developed mobile applications: highly demanding applications with simulations or dynamic graphics can be very attractive and probably more useful for explaining or clarifying physical phenomena, but we may find out that many students are unable of running them comfortably in their devices. On the opposite side, too much simple or static applications can be considered less interesting or useful and do not attract students to work or study with them.

Moreover, the costs associated with the use of mobile technologies to access the learning contents or to contact with other students or the teachers is a problem that cannot be neglected, specially when trying to apply mobile learning to less economically favored environments [VALK2010]. These communications among students or with teachers are strong points that can improve learning, as has been proved in other works encouraging interactivity using mobile devices [13, 14]. However, a possible limitation of those communications was the cost associated with the necessary connectivity [13, 15].

Finally, a last issue is whether mobile applications are designed only as learning tools or if someone also plans to use them to asses the students' work and learning. Some works have proposed to use the mobile devices as additional channels of a personalized evaluation of knowledge [16] or to facilitate assessment in classrooms [17, 18]. However important security issues must be addressed here to guarantee the proper evaluation of the correct student.

We have developed several applications in order to address some of the discussed points above and a survey was conducted to obtain the students' opinions on their work with the mobile applications as part of their autonomous learning. Some of these opinions are summarized in Section 4. Most of the applications developed by our group follow a similar structure, resembling the one shown in the screenshot of the main menu of one of the developed applications depicted in Figure 1. As can be seen there, the applications include several theoretical descriptions on the physical phenomenon described in the application. Once the student has reviewed those contents he/she can use the self-evaluating test in order to find what he/she has or has not understood or learned correctly. The core of the app consists of a simulation oriented to a better understanding of the physics of the considered phenomenon. As an example, Figure 2 shows four screenshots of the simulations included in different applications developed by our group. Finally, the possibility of sending some data on the students' work with the application, as the time employed reading the theoretical sections and the results obtained in the simulation, was also implemented. The global assessment of the students work is alter sent to the teacher, either by email or by storing it in a server.

Figure 1. Screenshot of the main menu of one of the developed applications showing the general structure of most of our applications.

3. USING THE SMARTPHONES AS MEASUREMENT DEVICES

Another possible use of smartphones applications for learning physics is using them to measure different quantities through their range of sensors either via *ad hoc* implemented applications or using others available in app stores. Many researchers have shown the possibility of using smartphones sensors both in laboratory measurements and in everyday activities. The use of smartphones as measurement devices has several advantages. On the one hand, it permits to have less expensive laboratories (i.e. *low-cost* laboratories) and, on the other hand it allows the students to make measurements of physical phenomena outside the teaching laboratories, taking profit of daily activities. Different examples of the use of general purpose applications that access the smartphones sensors in students' laboratory measurements can be found in several physics fields as mechanics [19-24], acoustics [25-27], electricity [28] magnetism [29] or optics [30,31]. However, some of these free applications lack the necessary tools to assess the accuracy of their measurements or even to analyze the influence of their use in different devices. This is the case, for example, of the required calibration of applications for sound measurement and analysis. In order to improve the lack of accuracy of accuracy, our group also develops applications that permit sensors calibration against laboratory measurement devices. In this way, these applications enable the students to make accurate measures with their smartphones both inside and outside the laboratory, whenever they carry out the mandatory calibration procedure. One example of these applications is shown in Figure 3, where two screen captures of an acoustics oriented application developed in our group are shown. By using this application, the students can utilize their smartphones as audiometer or sonometer, as well as learn some acoustics fundamentals.

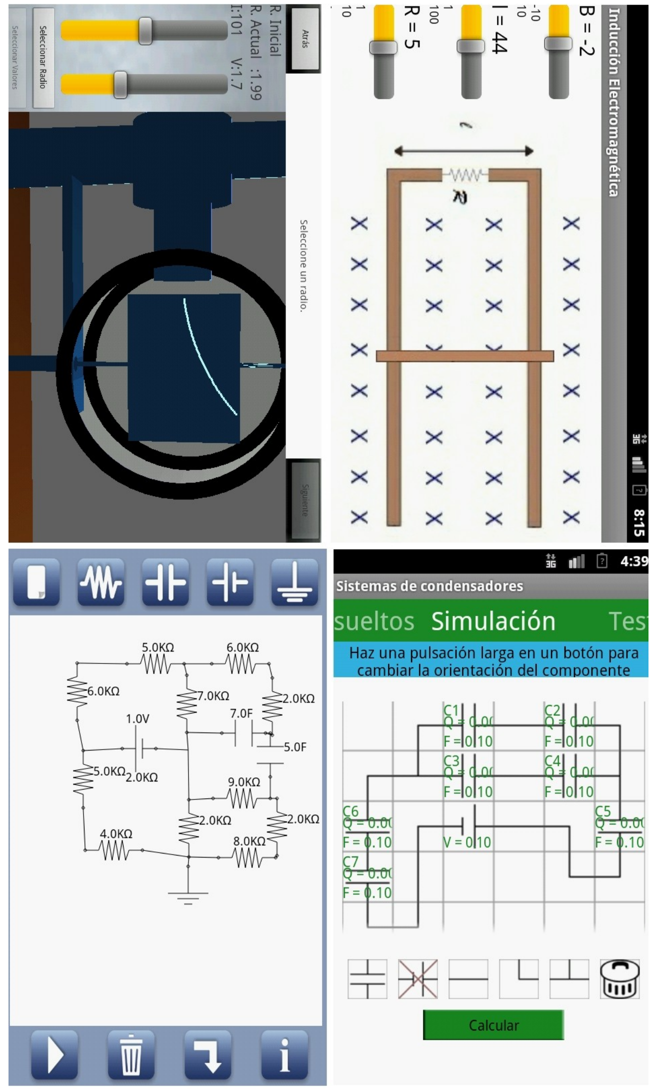

Figure 2. Some screenshots of the simulations included in four different applications. From top to bottom and left to right, we have the measurement of the ratio q/m for an electron using Helmholtz coils, a simple electromagnetic induction experiment, and application to build circuits and solve them using Kirchoff's laws and another one to obtain the equivalent capacitance of a set of capacitors in a circuit.

Another useful way of teaching physics is including learning as part of the students' everyday, or nearly everyday, activities so that they can use their devices to find out how the concepts learned in the classroom apply to their lives [32-36]. For example, Figure 4 shows the three components of the acceleration obtained placing a smartphone on an elevator floor while this performs a short descent between two storeys.

Figure 3. Two screenshots of two of the menus in one of our applications on sound measurements. As this application was developed in order to check if smartphones could be used as reliable laboratory devices, an important point in its development was the inclusion of a calibration of its microphone and speaker.

Data in Figure 4 was recorded using the free Android application Accelerometer Monitor [37]. From a simple measurement like this, the students can understand the decrease/increase of weight that they feel when the elevator starts/stops the descent (opposite for an ascent ride, of course). Even more, students can also obtain some interesting conclusions after an easy numerical analysis of the accelerometer data shown in Figure 4. For example, the integration of the a_z curve (after subtraction of the gravity component) allows them to obtain the change in the speed of the elevator, as seen in Figure 5, and once the speed was obtained, the total traveled distance could also be obtained and compared with the difference in height between the starting and ending floors. In the same way, from the acceleration and deceleration areas in Figure 4 the students could also prove the impulse-momentum relationship studied in the classroom or even analyze the oscillations that appear in the deceleration interval due to the inertia of the elevator, when the elevator engine is stopping, that produces a small elongation of the steel wire rope that holds the elevator and afterward some weak damped oscillations.

More complex measurements and analysis can be performed in other everyday activities as well, for example as the students travel in the underground or in a bus. The higher difficulty of measuring the acceleration in these other activities would teach the students the importance of accuracy in physical measurements. On the other hand, they could also obtain enriched results as the comparison with, for example, GPS data could allow them to understand the change in the acceleration components along the trajectories, centripetal acceleration in the curves, etc.

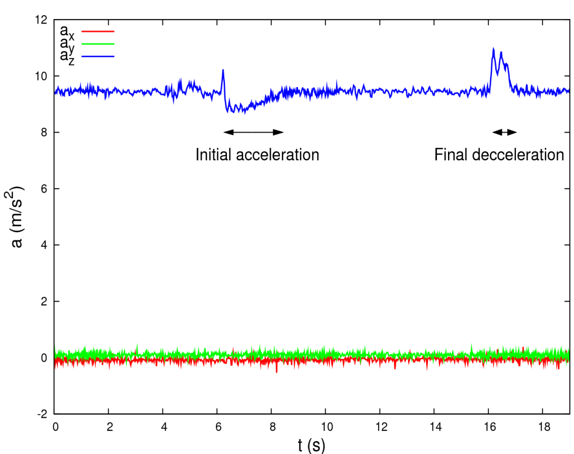

Figure 4. Measurement of the acceleration components along a short descend in an elevator. In order to reduce a little the experimental noise the values represented here for the acceleration were calculated averaging three neighboring points in the original data file.

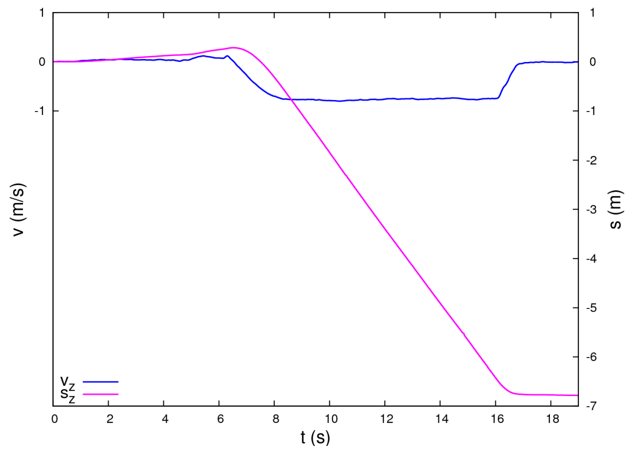

Figure 5. Calculation of the descent speed and the traveled distance from the accelerometer data. The noise in the first seconds corresponds to the experimenter's movements within the elevator and the start of the elevator engine. This measurement was done in a building for scientific and technological research whose storeys are higher than usual for normal buildings, as can be seen in the figure.

4. KNOWING STUDENTS' OPINIONS

In order to obtain students' feedback on the use of mobile applications for learning physics a survey was implemented. The use of a survey (in most cases as a Likert-like questionnaire) as a research method is a usual technique in many studies on mobile learning [8, CHE12]. Then the students were questioned on the applications we had developed and offered. The research questions we wanted to answer with the survey were:

1. What is the interest of students in mLearning as a complement to their formal learning?.

2. Do students accept the additional work of using the applications? or, do they see it as interesting and useful for their learning?.

3. How do students accept the costs associated with mLearning?.

The questionnaire discussed here, with a Likert 5-point scale format (with *strongly agree* as 4, *neutral* as 2 and *strongly disagree* as 0 on the Likert scale), consisted of 15 questions and 62 students answered the survey. Tables 1 to 3 show the study results. In the row corresponding to each question, the percentage of answers received for each Likert value as well as the average value and the standard deviation are depicted.

Results about the didactic effectiveness of the applications are shown in Table 1. Several points can be discussed here. As seen from the answers to question 1 on the tools offered by these applications to support learning, the students consider that the use of the developed applications is a good method for helping them learning. This result is also reinforced by the average values of the answers to questions 3 and 5, which show that students feel encouraged to learn more after using them, and also that their use is interesting and amusing. These are important conditions to enhance the student's work with the applications and improve their engagement. From the results of question 2, we see that a high percentage of students consider positive or very positive to include communication tools within the applications to ask questions or discuss concepts with the teacher or other students. This is not surprising because interacting with the teacher or other students are important features that improve learning [1]. However, the possibility of having a large number of students asking questions anytime to the teachers through the applications would discourage the educators to use these mobile applications. In order to cope with that drawback a forum solution for the communications has been chosen for next applications. A last comment on this set of questions is required for question 7. As can be seen from the results of this question, there is a larger dispersion in the results while also the average answer is the smallest. That seems to indicate that many students are pleased to use the applications to learn, but they are not so pleased with having their work with the applications graded. This result that has also been observed in other active learning environments: while most students acknowledge the benefits of active learning, still many of them prefer to procrastinate their evaluation to a last exam.

Finally, an assessment of the influence of using the developed applications on students learning and engagement was performed. For this, we compared the grades and participation of the students who did and who didn't use the developed applications. The results in two tests performed at the beginning of the semester were used to analyze if there were any initial statistical differences between those two groups of students, and after a student's t-test we concluded that both groups were statistically equivalent. At the end of the term the grades of the two groups of students were compared. From the results of this analysis, we concluded that the influence of the small set of applications developed till now on the students' grades was negligible. This result must not be considered a pitfall of the applications or of mLearning. We must take into account that only a small set of applications was implemented and that these applications covered only a small part of the contents of the subject, so that the influence on the grades obtained evaluating the knowledge of the students on the full contents should, evidently, be very small. However we found an interesting result related to the participation of the students in different subject activities, what was considered as a measurement of their engagement. From these participation results the percentage of students who used the applications and participated in different activities along the term was, in average a 17% higher than the percentage of students who did not use the applications. This percentage increases to a 54% when we consider only the participation of the students in the final exam. Though this analysis can be considered only as a limited measurement of students' engagement, the results obtained measuring the participation in different activities are consistent and support the conclusion that the use of these mobile applications attract the students towards the subject increasing their participation and engagement.

strongly disagree				strongly agree	Average ± st. dev.
0.0	1.0	2.0	3.0	4.0	
1.- The application facilitates tools that support learning.					
0.0	1.9	3.3	38.9	55.9	3.5 ± 0.7
2.- It would be interesting to include in the application communication tools with the teacher or with other students.					
5.20	9.4	18.4	32.8	34.2	2.8 ± 1.0
3.- The application stimulates curiosity and learning.					
0.0	1.5	24.4	43.7	30.5	3.0 ±0.8
4.- The application permits to develop activities that may be difficult to have in a more traditional learning.					
1.5	13.5	21.4	38.6	25.1	2.7 ± 1.0
5.- The use of the application is interesting and amusing.					
0.0	5.2	30.5	40.4	24.0	2.8 ± 0.9
6.- The test included in the application is an useful tool for learning.					
0.0	0.0	14.6	47.9	37.5	3.2 ± 0.7
7.- The teacher should consider the effort made using the applications in the course evaluation.					
5.9	0.0	37.9	20.8	22.9	2.4 ± 1.0

Table 1. Questions and results for the didactic effectiveness of the applications. An interesting point here is that for most of the questions the results lay within the high interval in the Likert scale. Only noticeable lower values are obtained when asking the students about the influence of the work with the applications in the students' grades

A possible important limitation of mobile learning is its cost due to the necessary expenses of devices, communication and required data transfer. So, the survey addressed this issue through three questions in order to know how the students consider this cost and if the learning compensates the necessary expenses. The results to these questions are shown in Table 2. As can be seen there, most students consider that mLearning costs are affordable and that the improvements in learning obtained through mLearning compensate the associated expenses. This must be taken into account if we plan to extend mLearning to less favored populations.

strongly disagree				strongly agree	Average ± st. dev.
0.0	1.0	2.0	3.0	4.0	
8.- The cost associated to mobile learning (device, connection …) is affordable.					
0.0	4.9	19.7	42.6	32.8	3.0 ± 0.9
9.- The cost associated with possible communications with the teacher or other students is affordable.					

0.0	6.6	19.7	47.5	26.2	2.9 ± 0.9
10.-What can be learn using these mobile applications compensates the associated expenses.					
0.0	8.2	18.0	44.3	29.5	3.0 ±0.9

Table 2. Questions and results on the perceived cost associated to mLearning. The general conclusion is that most students consider that what they learn compensates the expenses

Finally, a set of questions about the use of the applications and on mLearning was proposed, and their results are shown in Table 3. The most interesting result of these last questions is that a majority of students see mLearning as a very positive experience as they would recommend it (average value of 3.3 in our Likert scale) and use again this type of applications (average result 3.2). It is also interesting to see their positive opinion on mLearning, as they consider that it facilitates the access to education (average value 3.5). This is an interesting result for anyone developing learning tools as these are more efficient if the students take them willingly and knowing the positive effects that they have on their learning.

strongly disagree				strongly agree	Average ± st. dev.
0.0	1.0	2.0	3.0	4.0	
11.- The application was easy to use.					
0.0	0.0	11.7	39.4	49.0	3.4 ±0 .7
12.- The use of the application was helpful.					
0.0	0.0	20.1	59.9	20.1	3.0±0.6
13.- I would use other applications like these ones.					
0.0	0.0	14.8	47.5	37.7	3.2 ± 0.7
14.- I would recommend other students to work with these applications.					
0.0	0.0	9.5	50.8	39.7	3.3 ± 0.6
15.- Mobile learning facilitates the access to education.					
0.0	0.0	6.7	40.0	53.3	3.5 ± 0.6

Table 3. Questions and results for the general conclusions set of questions. It is interesting to notice that all the students' answers lie within the good or very good (2 to 4) Likert interval, probing that for the students this has been a very satisfactory experience.

5. CONCLUSIONS

The use of mobile applications, either developed by our group or freely available in app stores, for teaching physics has been discussed. Current capabilities of mobile devices allow us to develop content rich applications that include explanations, self-evaluation tests and simulations in order to help students to access the subject contents anytime and anywhere, and that represent a benefit to the traditional classroom teaching. By running some of these applications to access their sensor recordings, the smartphones can also become a natural component in the physics teaching laboratory. From an economical point of view, this may be an important point for the use of smartphones, as they may become a versatile element that can substitute other more expensive measurement devices. Students can also use the smartphone sensors in other activities to understand how some of the theories learned in the classroom apply in their lives. Finally we conclude, from the results of our survey, that the students believe that using smartphones as a complement to their learning is very positive. The students see the applications as very useful tools and are willing to use similar developments in other subjects. From a quantitative analysis, the use of the developed applications strengthened the interest of the students in the subject and noticeably reduced dropouts.

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