Smartphone based laboratories: a case study to measure friction coefficients

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ABSTRACT. The use of didactical laboratories is a common necessity both for distance and traditional universities. If in the first case institutions have to invest money not only in the creation but also in the maintenance of the structures, for distance learning there is an always under discussion problem related to how laboratory activities can be offered to students. In this context, smartphone applications can help both cases offering simple, low cost and didactical effective laboratories. In this paper, a review of the state of art is presented together with a case study realized during the annual internships organized by INFN-Frascati for secondary school students.

KEYWORDS: *Inclined plane, Laboratory, Online learning, Smartphone, Traditional learning*

The importance of laboratory activities in learning process

The presence of equipped spaces to realize didactical laboratories is mandatory not only at university but also at secondary school (Tobin, 1990). These activities are fundamental for various pedagogical and didactical reasons. First of all, as clear to everybody, during these activities we can better teach to our students how to work in team. This skill is strongly requested by nowadays labor market due to the always increasing number of work requiring specialized groups of people. Moreover, the possibility to realize "in real world" what studied during lessons or on books permits to increase the learning process facilitating students to understand concepts that could results difficult to learn (Novak, 2006).

Following these assumptions it is clear that the use of laboratories is not only exclusive for STEM courses (Science, Technology, Engineering and Math). Obviously, for these last subjects we can simply imagine activities in which students reproduce or apply theorems and results but the use of, for example, case studies and work simulations is useful for every subject offering the possibility to reproduce real work situations.

Problems related to the laboratory in traditional institutions

As discussed in the previous section, the use of didactical laboratories can strongly improve learning process developing important skills in our students. Now, if from a pedagogical point of view this concept is well clear, in "real life" we have to fight with often-unsolvable problems. First of all, the cost of a didactical laboratory is not negligible especially when considering the economical difficulties in which various institutions are. Moreover, when planning to organize a laboratory, we have not to consider only the starting price for the purchasing of the equipments but we must think also to the maintenance cost that represents a large fraction of the cost related to laboratories.
Moreover, to have a didactical effective laboratory we must offer to our students a sufficient number of "stations" intended as single and independent workbenches (Oakley, 2004). This aspect is fundamental when measuring the didactical effectiveness of an activity. In fact, during laboratory, our students will be divided into groups. The number of components of each team is not determined simply dividing the number of students for the number of stations but depends on the specific activity to be realized. A work-group must reproduce a real work simulation and this means that each component of the team must be in charge for a specific task. Unfortunately, very often, this is not possible because institutions can offer a limited amount of workbenches and instructors are forced to create "unnatural" groups.
If the problems in traditional institutions are strictly related to the cost of the laboratories realization and maintenance, when discussing distance learning we have a completely different situation.
Surely, what we affirmed concerning the pedagogical importance of labs is obviously valid also for distance learning. During last years, this kind of teaching approach has grown very rapidly and today this approach is widely used worldwide not only at university level but also for lifelong learning, workers update, secondary schools, etc. (Docebo, 2014). This cited trend is strictly related to the large amount of investments that have been made by universities to offer something that can be considered equivalent to traditional face-to-face learning. In this context, one of the still most studied sectors for the improvement of distance learning is exactly the possibility to insert or reproduce laboratory activities with students that are not present inside the university. Literature is plenty of examples in which various groups worldwide have formulated hypothesis or realized case studies to supply laboratory lack.
Nowadays, there are various possibilities to offer didactical experiences to students enrolled in distance learning (Martini, 2014a) and, in particular, they include: laboratory simulations, modern technologies and smartphones based laboratories.
Concerning simulations, this is a well-known and developed sector for distance learning. To be precise, in this category we include: multimedia products, virtual case studies, digital experiences, etc. In other words, a large amount of possibilities offered by modern technologies and usable for learning aims.

Even if the computer simulations are a well-established technology, some criticisms can arise due to the strictly virtual realized experiences. In this case, and always thinking about distance universities, a possible solution can be obtained using boards like Arduino or Raspberry Pie (Martini, 2014b). This quite novel technology offers the possibility to realize different types of laboratories not only reserved for STEM subjects. In particular, due to the extremely low cost of the boards themselves, dedicated activities can be assigned to students to realize specific laboratory equipments. As an example, in Figure 1 we show a pH-meter realized with Arduino (Kubínová, Šlégr, 2015). In this case, different students can be organized to manage specific parts of the work: mechanical structure (if needed), software, electronics design, electrics realization and so on. The result of these activities is double: first of all, we can create the desired multi-skills teamwork and then the final result of each activity is a laboratory equipment itself. In other words, always considering the pH-meter of the example, this is a real low-cost instrument that can be used for chemistry laboratories.
Concluding this part, one of the most promising solutions to include laboratories in distance learning, but also to offer a valid alternative to traditional face-to-face institutions, is the creation of smartphone-based experiences. In the following sections this possibility will be deeply discussed showing also a case study performed with secondary school students.

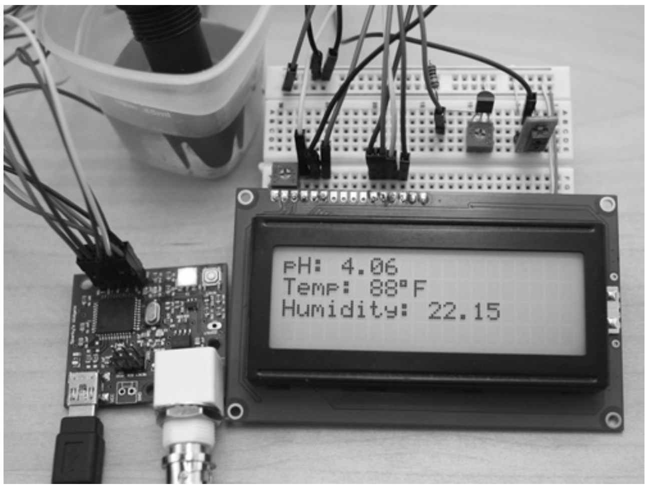

Figure 1. pH-meter realized with Arduino. The system also permit to measure temperature and humidity in a chemical solution

Modern smartphones

Before discussing the possible use of smartphones to realize laboratory experiences we have to briefly analyze what these systems can offer.
If, up to some years ago, smartphones represented a small sector of the mobile solutions, nowadays these devices represent the majority of the mobile phones available on the market (Goasduff, 2012). The distribution of this technology has implied a rapid decrease of the price together with always-improved characteristics.

Today, smartphones are very sophisticated instruments equipped with:

- environmental sensors;
- a large number of software to acquire and manage data;
- internet connections;
- communication systems;
- very fast electronics;
- miniaturized chips permitting small and light package.

and, moreover, "they also permit to make calls". Unfortunately, even if, as already said, they are very well distributed, in the majority of cases, smartphones are only used to navigate on Internet.
Concentrating the attention on the sensors equipment, in every device we have:

- light sensors to modify screen brightness;
- proximity sensors to switch off screen during calls;
- touch screen;
- magnetometer;
- barometer;
- gyroscope;
- accelerometer;
- GPS;
- wifi;
- bluetooth;
- near field communication system;
- camera.

Each of these sensors is used for a specific item during functioning or, in many cases, is exploited to play in a more realistic way videogames.
If we consider this equipment from a didactical point of view, we can realize that each sensor can be used as a portable measurement system to organize didactical activities.
There are some additional considerations to be done in this context. As discussed in the previous section, one of the main problems of traditional institutions is the lack of money to create or maintain laboratories. The possibility to exploit smartphone to realize these activities is completely costless for universities and schools since students can use their own smartphone. In the very rare case in which some students do not own these devices, institutions could provide a small number of smartphones with a very small investment. Moreover, we have to take into consideration also another pedagogical aspect; as clear, students entering now into universities and schools are part of the so-called "digital generation". For these scholars the use of smartphones is natural, familiar and well known. Involving these devices into learning process students are intrigued hence they better follow activities.
Obviously these last assumptions are true both for distance and traditional universities. In particular, exactly because students are using their smartphones, these experiences can be realized at home, at schools, singularly, in groups or in every configuration instructors want to use.
As already discussed, the literature on this sector already offers a large amount of works and case

studies realized both in universities and in secondary schools but this activity is still very poor especially when considering the potentiality of these applications.

Smartphone as particle detector

Just to give an example of the potentiality of these solutions and on the available literature, we include in this section an interesting application developed by researchers of the Wisconsin Ice Cube Particle Astrophysical Center (WIPAC website).
As everybody know, the camera available in our smartphone exploits a CCD (charge-coupled device) composed by a certain number of pixels (Carlson, 2002). A greater number of pixels into the matrix mean a better resolution achievable with our camera. A clear example of this property is shown in Figure 2.

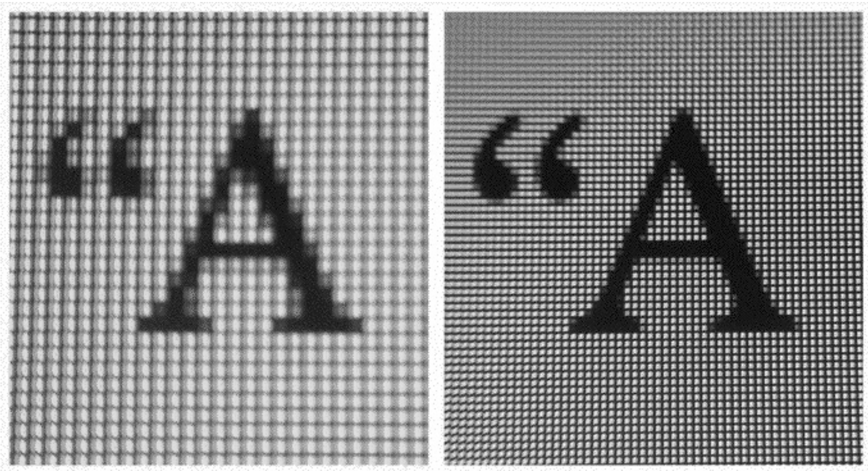

Figure 2. Same symbols displayed on screen with different pixels number

Not going in details, the pixels of the CCD are excited by the passage of light i.e. of the electromagnetic radiation (Peterson, 2001). In other words, each radiation passing through CCD excites the pixels. Now, this property can be exploited to transform our smartphone into a particle detector.
First observation: to observe particles passage we need a source of particles! In this case, and if we want to demonstrate to our students the existence of particles, we cannot use light. In this specific case, we can use cosmic radiation. As we know from physics, every part of the Earth surface is continuously bombarded by cosmic muons produced by particle coming (principally) from the Sun and interacting on the top layer of our atmosphere (Berezinskii, 1984). This process is well described in Figure 3.
Using cosmic rays we can reach a double result from this experience: first, we demonstrate to our students a possible different solution only based on smartphone, second we show to them the passage of cosmic rays. This last sentence is not trivial because people are not accustomed to observe, also indirectly, the passage of something that is not visible by their common senses.

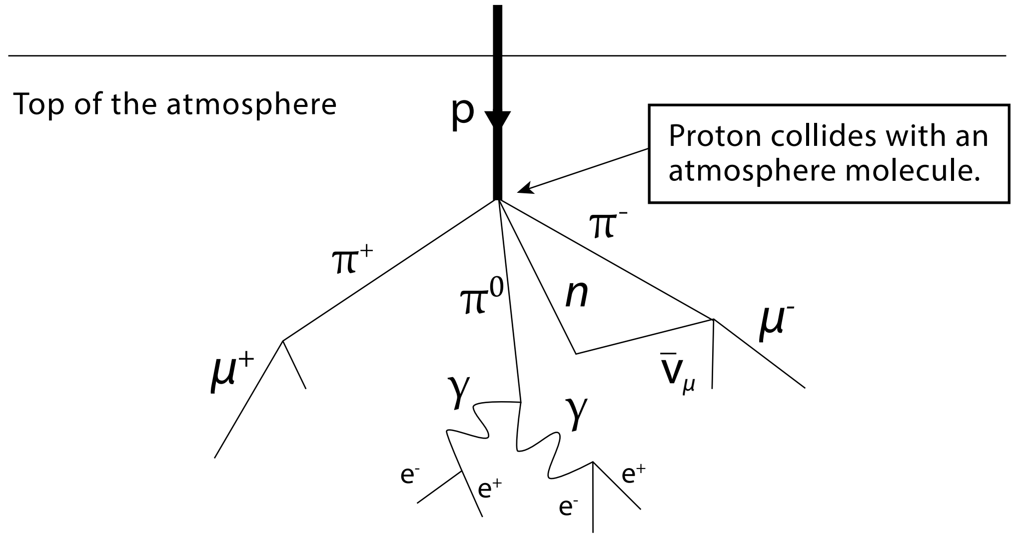

Figure 3. Cosmic rays shower. A primary proton collides with molecules in the top of atmosphere producing a secondary shower. Neutrinos and muons reach Earth surface

Now, the only thing we need is a specific application to show particles passage.
As already discussed, this application has already been developed, is available for Android systems (iOS version under development) and is named DECO (DECO website; Figure 4 is a screenshot of the application). The application consists of two different apps, an online monitor and a data logger, necessary to run the software.

Figure 4. Screenshot of DECO application

Before using DECO a fundamental precaution must be followed. The number of cosmic rays detectable using this app is limited by CCD area. To obtain a first guess on the number of the particles, we can assume a rough number of 1 particle per second per centimeter square arriving to the surface (to be precise the number of particles strongly depends on the energy considered and then on the sensitivity of the CCD). Rescaling for the sensor area we have a rough guess on the expected flux. Due to this number, it is well clear that the environmental light gives a dominant contribution to the signal completely covering, if not eliminated, particle signal. To cancel out this background we can use standard black tape to cover the CCD allowing only the passage of the cosmic particle (not stopped by tape).
This example is reported only to show an application able to exploit smartphone sensors. As discussed the didactical utility of this experience is well clear and, as observed by us during activities with students, young scholars are attracted by every activity they can realize with their smartphone.

Case study: measurement of the friction coefficients

One of the most common laboratory experiences that are performed into secondary schools and universities, in the context of Basic Physics course, is the measurement of the friction coefficients using different materials. Even if there are various experimental solutions to measure these parameters, the simplest equipment exploits an inclined plane.
The experimental scheme is shown in Figure 5.

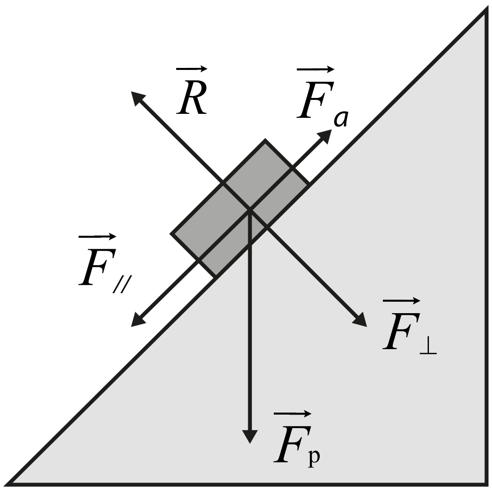

Figure 5. Parallel and transversal to plane components of the weight force on an inclined plane

In this case, the experiment consists of two different steps. In the first part, the plane starts horizontally and the angle is increased step by step. When the angle is not zero, the body tends to slip pushed by the longitudinal (to the plane) component of the weight force. This motion is opposed by static friction force depending on the transversal component of the weight force and on the static friction coefficient (Resnick, 2001).

The simple relation is given by this formula:

$$F_{//} = mg\sin\vartheta \leq \mu_s mg\cos\vartheta = F_{sf} \qquad (1)$$

where: $F_{//}$ is the component of the weight force parallel to the plane, m is the mass of the body, g is the gravitational acceleration, θ is the angle, F_{sf} is the static friction force, and μ_s is the static friction coefficient.
When the angle reaches a certain value, the body starts to slip since we reach the equivalence in the expression (1).

Measuring this angle, we can evaluate the static friction coefficient that only depends on the materials used (both for plane and body).
When the body is in motion on the plane, we have a different (lower) friction force that depends on the dynamical friction coefficient.
In the second part of the experiment students set an angle that is greater than the limit value obtained in the first activity (to permit the slip of the body) and they can measure the time necessary to reach the end of the plane starting from a certain height. Since during motion the body is subject to a force that is the resultant of the longitudinal component of the weight and the friction force, this time depends on the friction coefficient (Resnick, 2001). In particular, the force acting on the body is:

$$F_R = mg\sin\vartheta - \mu_d mg\cos\vartheta$$

where μ_d is the dynamical friction coefficient.
To perform this measurement we need some experimental equipments. For the first part, we must only measure the angle in which the body starts its motion. On the contrary, in the second part, we have to measure the time necessary to reach the end of the inclined plane. With normally experimental setup this is possible using two photocells used to give start and stop to a chronometer. Even if we are describing a very simple experience, the didactical utility of this activity is well clear. Unfortunately, as described, to perform this experiment some tools are necessary. At the minimum level, two photocells and a remotely controlled chronometer are required and these are very fragile parts and often requiring both ordinary and extraordinary maintenance.

Students internship at INFN-Frascati

During the period 6-10 June 2016, Frascati National Laboratories have organized the 16th edition of the "Residential Internships" for students of the 4th year of secondary schools (STAGE website). Scholars involved in the project came from different parts of Italy and they have been selected in their schools choosing students with the higher results in scientific subjects. During this event, specific seminars are organized to explain basic and modern physics, the latest results in high-energy physics and to discuss the next challenges in science and technology. A fundamental part of this event is represented by the experimental activity. Students are divided into workgroups and each team is sent to a different laboratory to perform experiments. During these days we were in charge for the presentation of the calorimetry sector in high energy physics and students had the possibility to build and set a dedicated experimental apparatus to measure some properties of scintillating fibers. Since we were working with secondary schools students, we included in this activity also a simple experiment for the measurement of the friction coefficients using smartphones. In our opinion, this additional experience was fundamental to show not only the status of the advanced physics but also to gift to students something that can be simply realized both at home or in their institute.
As we observed during experimental activities, a large fraction of the students never entered into a laboratory in their school confirming what discussed in previous sections.

Smartphone-based measurement of the friction coefficient

Following the prescriptions discussed in the previous paragraph, we built a very simple experimental setup to measure both statics and dynamics coefficient, as shown in the below figure.

Figure 6. Experimental setup to measure friction coefficients using smartphone

We prepared three different planes using: aluminum, brass and steel. The height of the system (and then the angle) can be regulated using a fine screw. A cart fixed on a brass carriage represents the slipping body. To avoid damages and permit a perfect contact between plane and cart, the slide has a groove with the same width of the plane. Using a very simple system made by elastics, smartphone was fixed on the cart. The use of elastics is not due to the impossibility to realize a mechanical structure but to the necessity to have a completely adjustable solution able to host different smartphones.

The execution of the experience follows exactly the same steps of the classical version with photocells. In the first part students measure the (limit) angle in which the motion starts in order to obtain the static coefficient, then they use different angles (greater than the limit value) to measure the time length of the motion thus obtaining dynamic coefficient. Thanks to the experimental setup, students can perform these measurements in different conditions:

- Using different planes (i.e. different material);
- Using different types of greases and oils to observe friction reduction.

For each configuration students were asked to perform a certain number of different experiments in order to evaluate also the uncertainty on the obtained result. In this way, we had the possibility also to teach some statistics notions and to explain them the importance of the uncertainties in experimental physics.

Useful APPs to perform the measurement

As explained in previous sections, our smartphones have a huge number of embedded sensors that are normally used during their functioning. To organize laboratories exploiting this tools we need to collect data acquired by sensors for recording and analysis. Today, both android and iOS can use a very big amount of free applications available in their markets. Obviously, there is also a long series of applications not for free that can offer additional tools but this sector will not be discussed in this paper since our aim is to offer completely (or almost) free solutions.
For the measurement of the friction coefficients, we use two different solutions, one "commercial" and one "custom" just to show to our students different possibilities.
Starting from the commercial solution, we use "Sensor Kinetics" (KINETICS website; Figure 7).

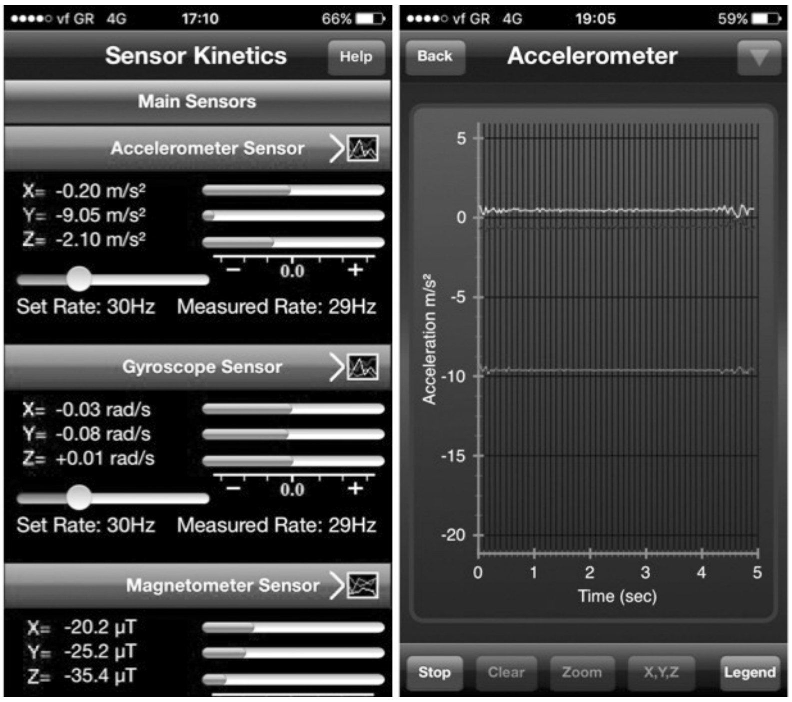

Figure 7. Left: screenshot from Sensor Kinetics app. Right: plot from Sensor Kinetic for accelerometers data

This app, available both for Android and iOS, permits to show and display data acquired by different sensors: accelerometer (in each axis), gyroscope, magnetometer (if available), linear acceleration plus some indirect parameters obtained combining sensors (Figure 7 left). The version available for free of Sensor Kinetics does not permit to collect data in a file. This additional tool is important for example to permit an independent analysis of the collected data using spreadsheet software. During the measurement of the friction coefficients we solved this problem using directly the plots displayed by the application (Figure 7 right).
For the first measurement of the static coefficient, students increase, step by step, the angle, observing directly the value of this parameter on the display of the phone.
For the measurement of the dynamic coefficient, since we are interested not in the absolute value of the accelerations along the axis (which do not change during motion), we use the linear acceleration

variation measuring directly from the plot the time interval in which we have variations (between the beginning and the stop of the motion).
A different possibility to measure physical parameters is offered by a custom developed application. In particular, we have used the Android "MIT App Inventor", provided and developed by Massachusetts Institute of Technology and Google, to prepare a specific app to collect data coming from accelerometer (MITAPP website). This tool permits to simply write (also in graphical mode) application for these devices with a set of pre-prepared code to access sensors, memory, time-stamp, etc. In the graphical interface of the program everyone can write his code, test it on his smartphone and finally produce the APK file for the installation on different devices. The use of this software permits us also to show to students a simple system to write application and to use their smartphones not only for the most common functions.
Using this custom app we have also the possibility to collect data in text version and manage these results to build plots, correlations and for a fine selection of the time intervals necessary to perform our measurement.
During this experience, students have the possibility not only to observe but also to become protagonists in the experimental activities. Thanks to this simple activity, we have explained different aspects related to: physics, statistics, mechanics, software development, smartphones, etc. These concepts can be useful not only during school life but also for their future job. As clear to all, most of these skills are now strongly required by labor market and our students had the possibility, for most of them for the first time, to observe directly these applications to stimulate their fantasy and interests.

Conclusions and future improvements

One of the main problems in the learning path of our students is in the difficulties that a large number of institutions suffer for the creation of laboratories. As discussed, in this case, even if from a different point of view, the possibility to insert didactical laboratory experiences is a fundamental aspect of the leaning of our scholars both for traditional and distance universities. Moreover, as evidenced in this paper, the pedagogical importance of these solutions is not strictly reserved for STEM subjects.
The main difference between traditional face-to-face and distance universities is that the first one have to take into consideration money necessary for creation and maintenance of the structures while e-learning is always looking for alternative solutions to provide at home activities.
Smartphones represent a well-distributed technology but unfortunately still under used. The possibilities offered by these devices are enormous and, exploiting their embedded sensors, they can offer alternative ways to create laboratory.
In this paper we introduced a simple example to show how a smartphone can be transformed into a particles detector together with a case study for the measurement of the friction coefficients of different materials. While the first application is important to stimulate the curiosity of our students really showing the existence of cosmic rays, the case study has been realized to directly measure the response of the students. In particular, this experiment has been realized during the internship of secondary school students in the Frascati Laboratories of the Italian Institute of Nuclear Physics. Even if the measurement uses a very simple setup, this activity, and all the one related to smartphones,

offers the possibility to show to scholars critical thinking on: physics, statistics, programming, electronics, mechanics and so on. During the laboratory realization students had the possibility to prepare specific apps and also to create discussion groups for the analysis of their results.
The most important conclusion of this case study is exactly in the curiosity of the students. Using smartphones to organize laboratories we are offering them something very familiar but from a different point of view. Last but not least, this kind of skills is exactly what labor market is asking now but unfortunately, for the reasons discussed in the paper, a large number of students has not the possibility to observe this concepts during their school life.

Acknowledgments

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Sintesi

Nella formazione didattica dei nostri giovani, di qualsiasi età, il laboratorio è e sarà sempre un aspetto propedeutico per acquisire capacità pratiche che, oggi più che ieri, sono ritenute indispensabili dal mondo del lavoro. Se questa affermazione può sembrare scontata e condivisibile da tutti, non è ugualmente certo che una scuola o una università abbia le risorse per potersi dotare e per poter mantenere attivi laboratori efficienti e moderni. Come risolvere questo paradosso? Sempre più spesso si parla di "mobile learning" per indicare una didattica che sfrutta i dispositivi mobili, siano essi cellulari, smartphone o tablet. Purtroppo però, ancora oggi, questi potenti strumenti di uso comune non vengono sfruttati a pieno ma, anche nel contesto dell'insegnamento a distanza, vengono utilizzati solo per fruire le lezioni. Come noto a tutti, questi dispositivi racchiudono al loro interno strumentazione di primo livello e un grande numero di sensori. Queste meraviglie della tecnologia possono essere trasformate in veri e propri laboratori tascabili semplicemente sfruttando nel migliore dei modi le loro potenzialità. In questo articolo viene presentato un caso studio proprio basato su un laboratorio di fisica classica realizzato con gli smartphone. Tale esperienza è stata realizzata all'interno dei Laboratori Nazionali di Frascati con gli studenti delle scuole superiori che, con risultati maggiori delle attese, hanno accolto con entusiasmo questa attività con cui hanno scoperto un mondo che avevano in tasca ma di cui ignoravano le potenzialità.