APPLIED ASPECTS OF INSTRUMENTAL DIGITAL DIDACTICS: M-LEARNING WITH USE OF SMARTPHONE SENSORS

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Abstract. According to the concept of the new Ukrainian school, the educational process is undergoing intense changes. This is partly due to the active implementation of a variety of information and communication technologies and mobile equipment. The article discusses the methods of use of mobile applications for physics study. Foreign and Ukrainian experience of using information-technological and technical capabilities of mobile devices for educational purposes is analyzed. The classification of mobile applications is proposed; methodological advantages and disadvantages of their use in the educational process are defined. Mobile applications are an important part of the digital didactics tools. Features of innovative teaching methods based on the use of the measuring, computing, and modeling functions of the sensitive elements of gadgets are revealed. It has been shown that the use of sensors in the teaching of physics is a kind of instrumental digital didactics. Besides, an example of application the Physics Toolbox Suite to perform a research on the topic Mechanics is described in the article.

Keywords: m-learning, smartphone, sensor, proximity sensor, accelerometer, mobile application, physics, instrumental digital didactics.

1 Introduction

Today, the most popular gadget owned by about 93% of students is a smartphone [1], which, in particular, creates conditions for access to educational programs, scientific materials, and mobile applications (MA) for field experiments. The proliferation of BYOD IT policies in the field of education [2, 3, 4] has led to an exponential increase in the number of pedagogical investigations about the use of various gadgets for teaching. Models of study with the use of smartphones, which have the common name m-learning, have acquired extraordinary development over the last 5 years. Therefore, on request for each of the keywords (m-learning, smartphone, mobile device) on the Research Gate platform you can get about 100 articles, the earliest of which are written, apparently, in 2014. However, much less scientific articles and messages can be found in the context of using smartphone sensors to collect and analyze data during educational studies in the field of natural sciences.

Special attention in the new standards of general secondary education is paid to the importance of developing the abilities to process experimental data using digital tools. The information-digital competence is admitted in the section «Natural education» of the new standard. The competence includes the ability to use digital resources to obtain new knowledge, search and process information of natural content, transform it using modern digital technologies and gadgets from one form to another. It is considered as know-how potential for modern industry.

An important role in research about using a smartphone is played by specialized mobile applications (MA), which over the years have changed from digital sensors *Datchiker* [5] to open platforms such as *Phyphox* [6], which process and analyze experimental data.

Some time ago recording applications had only the function of exporting spreadsheet data. On the other hand, practice has shown that experimental data analysis is time consuming and requires the use of data processing tools (eg Excel, MathLab, MicroCal Origin, etc.). Furthermore, in students' minds there is no stable logical connection between the essence of a physics phenomenon and its mathematical description.

2 Analysis of related research

The use of mobile technologies as a means of teaching physics has been the subject of research by foreign and Ukrainian scientists. In particular, the importance and influence of information resources for the modern educational process were investigated by V. Bykov [7], M. Kyslova et al. [8], I. Salnik [9]; theoretical aspects of mobile learning were considered in collective methodological recommendations [10] and an article of N. Rashevskaya [11]; possibilities of mobile technologies using in the educational process were investigated by A. Babich [12], Y. Modlo et al. [13], J. Kuhn and P. Vogt [14], V. Sipiy [15], G. Skrypka [16], S. Tereshchuk [17]. They are devoted to the problem of peculiarities of the use of mobile technologies during the study of the natural and mathematical disciplines. O. Slobodyanyk [1] exploring m-learning as a pedagogical tool reveals the main advantages (mobility, accessibility, compactness, speed, modernity, personalization of learning, instant feedback, effective use of time, continuity of the learning process, qualitatively new level of control of the learning process) and certain risks that may reduce the effectiveness of mobile devices usage in school practice.

On the other hand, as noted in [1], m-learning technology as part of digital didactics alongside with refining students' motivation to study the subject, shifting the focus to the learning process interactivity can take out research from the laboratory, turn the gadget into a means of cognition of the laws of nature.
The use of the BYOD approach as a tool of control of students' knowledge has been proposed in [18]; it also is possible on the basis of the *Lab4Physics* app for carrying out frontal physics laboratory works [19].

It should be noted that the research of foreign scientists is more focused on certain applied aspects of m-learning. J. Traxler [20] demonstrates the ability of mobile devices to extend the range of time frames of information perception. Application of MA in university education and training of future specialists was investigated by D. Parsons [21], N. Keskin and A. Kuzu [22], M. Alqahtani and H. Mohammad [23] M. Bice et al. [23]. The problems of implementation and use of mobile devices in the teaching of physics were investigated by A. Kaps and F. Stallmach [25].

Pierratos and Polatoglou examines the use of Phyphox MA to study uniform motion using an optical stopwatch based on the action of a smartphone photosensor. There is also attention to the convenience of using smartphones during lectures by means of projections of the teacher smartphone screen [26].
An original training method for measuring kinetic friction coefficient using an accelerometer and inclinometer of a smartphone and MA *Physics Toolbox Sensor Suite* [27] was proposed by A. Çoban and M. Erol [28].

Interesting experiments focused on overcoming the problems of studying the relationship between force action and body acceleration using the MA Physics Toolbox Sensor Suite are suggested by the authors [29].

Overall study of the development of MA for processing data from smartphone sensors (more than 30) as well as some examples of techniques for using the most popular ones (Physics Toolbox Sensor Suite and Phyphox) are presented in [30].
However, detailed analysis of scientific and pedagogical sources shows that it is very relevant now to research and systematize the methods of using MA as a practical tool for educational research conducting during physics study.

3 The purpose of the article

In the context of the natural sciences study (especially physics) it is important to create such methods that combine a full-scale (real) experiment with digital analysis and interpretation of the obtained data. For a long time pedagogical innovations in this context were focused on the use of digital measuring systems for laboratory purposes. Nowadays, serious instrumental competition has created by smartphones that contain sets of sensors and related software; they are suitable for full-sized educational research, in particular, for distance learning. This aspect, in our opinion, is a key argument that m-learning in 2020 takes a firm position as an educational technology on the Plateau of Productivity Trends on eLearning Hype Curve [31]. Therefore, the aim of the investigation was to analyze the existing types of MA used in the teaching of physics as well as to demonstrate the technology of determining priority of MA suitable for creating effective educational research using field experiments.

4 Results and discussion

Classification of MA according to the didactic purpose.
All mobile devices have software applications that are installed in the device itself or can be downloaded from the online mobile app stores such as the App Store, Google Play, Windows Phone Store for free or for money.

The analysis of various sources of technical, technological and pedagogical data makes it possible to divide all mobile applications into four classes according to the didactic purpose (Fig. 1).

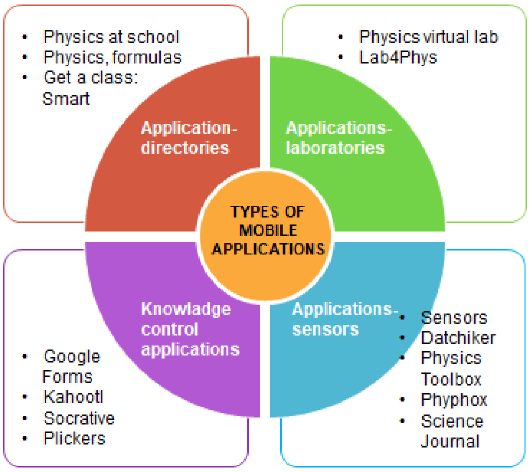


Fig. 1. Classification of MA according to the didactic purpose

A special feature of these MA-directories is the availability of physics course material, which is structured into sections and topics. It can help in an easy and accessible way to understand the essence of physics phenomena.

Applications for *knowledge and skills controlling* represent a multi-level system of tasks. They are designed for easy test or survey results processing.

Virtual laboratories are advisable to use for educational physics experiment, demonstration of phenomena, structure and properties of real and artificial (technical) objects, various simulations; the laboratories also have interactive mathematical tools for experimental data processing.

In our opinion, sensor applications as platforms for obtaining and analytical processing of data from a smartphone sensors during full-scale (non-virtual) experiments deserve special attention.

Physics at school [32] is Android compliant MA that has 16 physics sections; it can help to understand the essence of physics phenomena in simple and accessible form using visual animation clips; it is freely distributed.

Physics. Formulas. 7-11 [33] contains reference material, equations for the school physics course; the material is structured by classes, sections, topics. Although the MA covers almost the entire physics course, some topics may be missing. This approach assumes that the student has basic knowledge of the subject. Thus, it is advisable to use the application rather as a guide when completing homework or students' independent work. It is freely distributed.

Physics [34] is intended for students with low or intermediate levels of the subject knowledge. The profile of «Physics» is presented in the form of a short guide where you can find not only equations and explanations for them but also physics laws with explanations. In total, the application has five sections each of which has from four to seven units. Due to its rather brief structure and availability of the material, this MA can be used instead of a textbook. The app is also free and available for devices running Android 4.0.3 and later. Among the drawbacks is slightly dull interface.

The Physics virtual lab [35] has an English language version only. This is a virtual physics lab, where everyone can check the basic laws of physics using touch control.

Particularly popular among teachers and students is the Get a class: Smart MA [36]. It provides many opportunities for studying physics from 7th to 11th grade. The program contains a separate section «Preparation for the External independent testing» where for each topic at least 20 multi-level tasks are selected. To make the learning process more interesting, a character named Smart is in the role of assistant in the application.

Control and evaluation of students' knowledge and skills is important part of the educational process. Usually, the teacher spends a lot of time preparing the tasks and checking their accomplishment. The *Google Forms app* [37] allows somebody to create large-scale surveys of different types of questions. It can be used both for classroom work and for long-distance surveying. Both options provide students with answers from their own mobile devices. *Kahoot Apps*! [38], *Socrative* [39], and *Plickers* [40] focus on rapid processing of test or survey results. This is especially important when the teacher is using a knowledge-based orientation test.

Note that the types of MA we have described can form hybrid, integrated digital platforms. This is especially remarkable on the example of the MA created at National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute». The Department of Physics has used one of the educational process support systems that enable students and teachers to work using mobile devices – LMS Moodle (Physics.zfftt.kpi.ua). The training materials on this platform can be presented in video and audio formats, in book format similar in structure to print publications, as well as in the format of lessons scheduled for weeks of work or topics for study. You can also download and play materials offline. The powerful testing subsystem due to the variety of test forms not only allows us to accurately evaluate the learning outcomes of students or pupils but also obtain the consequences of statistical processing of the results; therefore, it is possible to determine the quality of the proposed tasks. The quality of learning can also be checked using the resource «Tasks»; it defines the task for fulfillment, which the student draws in the form of a file and sends it to the teacher for review. Chat, Forum, Seminar, and others are essential for teamwork skills formation. All these capabilities determine the widespread use of Moodle to support both traditional and distance learning.

Features of Smartphone Sensors.

Modern smartphones are powerful and sophisticated devices. Smartphones combine various subsystems such as communication module (calls and Internet, Bluetooth, Wi-Fi), navigation system (GPS, QZSS and others), sensor set, I / O device (keyboard display, speakers).

The electronic elements responsible for the implementation of such functionality are located on a common physical platform (card). The operating system (OS) integrates at the software level all the components to perform the specific tasks of this device. The performance of modern processors is largely determined by the number of cores that also determine the number of simultaneous execution threads. Different smartphone equipment performs the same task (scaling property). Modern smartphones use UNIX-similar portable operating systems such as Google Android, Apple iOS.

The implementation of these systems began with the creation of compact computers, which at the same time contained sufficient hardware (performance and clock speed of the processor, amount of RAM). Modern budget, mid-range phones offer the ability to use, for example, analytical MatLab software.

The performance of modern processors is defined by the architecture used and the number of information flow streams: 1.8 - 2.8 GHz and up to 12GB RAM.

Important physical elements of the smartphone are the sensitive elements that provide the measurement process.

In general, sensors of modern mobile phones can be divided into three categories:

1. *Motion sensors* (for example, an accelerometer measures acceleration values simultaneously along the X, Y, Z axes, determines the position of the device in space, setting its angle of inclination relative to the Earth's surface; thanks to the accelerometer, the gadget responds to overturning, shaking, or shock; gyroscope responds to the change of rotation angles around the three axes of coordinates with the tracking of movement relative to three planes simultaneously that allows to determine the orientation of the device in space);
2. *Position sensors*, such as a magnetometer (measures the magnetic field along the X, Y, and Z axes as well as the magnetic properties of materials), GPS (used to navigate or locate coordinates), proximity sensor (chip to track how close a smartphone is located to any object).
3. *Environmental sensors*, such as light sensor and barometer.

It should be noted that methods of study using smartphone sensors can be focused not only on obtaining experimental data but also on the study of the structure and physics principles of operation of these high-tech devices themselves.

The principle of accelerometer operation, otherwise called the G-sensor, is based on the inert properties of the bodies during their motion with acceleration: a load of a certain mass is fixed between the spring and the damper, which are attached to the frame. When moving with acceleration the force leads to deformation of the spring. The extent of deformation determines the device acceleration. The damper dampens the load vibration. G-sensor for smartphone has an electromechanical chip design.

The most widely accelerometers are used in aircraft navigation devices, car DVRs and speedometers, industrial vibration control systems, information systems for protecting hard drives, as well as in various gadgets.

Likewise, the proximity sensor is worth considering; it tracks how close a smartphone is to an object. Its main function, which was first installed on a Nokia phone, is to turn off the display when lifting the phone to your ear to prevent accidentally tapping the touch screen with your cheek or ear while talking. Also it saves battery power during long-term calls as the display consumes a lot of power. In addition, the proximity sensor can be used for gesture recognition and the camera focusing.

Detection of the distance most often acts on the principle of radar: the smartphone emits infrared rays, which in the case of any obstacle reflect on it and the reflected signal is caught by a special receiver. Note that there are already sensors «Ellipticlabs» that use ultrasound (imitating bats). This does not require major changes in the design of the smartphone since the ultrasound is emitted and received by the speaker and the microphone of the device.

Research on the hardware and operating parts of the smartphone.
Note that the smartphone capabilities to measure and analyze physics quantities are determined by two main factors: the presence of sensing elements - sensors as well as the type and generation of OS.

The OS version also identifies MA that can be installed on a smartphone. In this context, we conducted a comparative analysis of the main characteristics of the popular brands of these gadgets, the results of which are summarized in Table 1. From the data we can see that in all modern models there are motion and proximity sensors, which we will use in the future.

The study also found that some types of smartphones can be equipped by sensors that can measure acceleration, magnetic field, light level, pressure, and temperature; however, the OS version does not allow installing MA designed for the older generation operating system. On the base of these conditions, we considered the most multipurpose MA focused on different versions of OS.

To find out the types of OS and available sensors as well as to evaluate the skills of using the MA as research tools we conducted a survey using Google Forms with the involvement of teachers and students studying at the National Pedagogical Drahomanov University, Kherson State University and National Aviation University (total 136 persons). One of the questions was to determine the characteristics of smartphones using the system menu of gadgets (Fig. 2). It was found that most of the respondents' smartphones use the Android operating system (Fig. 2a).

Table 1. Comparative analysis of the main characteristics of popular brands of gadgets

Brand	Apple	Xiaomi	Meizu	Samsung	Samsung	CAT
Model	**iPhone 11**	**Redmi Note 8 Pro**	**X8**	**A30s**	**Galaxy S4**	**S60**
Processor	Apple A13 Bionic; 7нм	MediaTek Helio G90T; 12нм	Snapdragon 710; 10нм	Exynos 7904; 14нм	Exynos 5 Octa 5410; 28нм	Snapdragon 617; 28нм
RAM	4 GB	6 GB	6 GB	3/4 GB	2 GB	3 GB
Accelerometer	+	+	+	+	+	+
Gyroscope	+	+	+	+	+	+
Light sensor	+	+	+	+	+	+
Proximity sensor	+	+	+	+	+	+
Compass	-	+	+	+	+	+
Face scanner	+	+	+	+	-	-
Fingerprint scanner	-	+	+	+	-	-
Hall sensor	-	-	+	+	-	-
Barometer	+	-	-	+	+	-
Unique sensors	-	-	-	-	Thermometer	Thermal imager

Note that anybody can check which sensors are on the smartphone with the help of many free downloadable MA such as Sensors MultiTool, Sensor Kinetics, Datchiker (for Android) and Sensors (for iOS).

The study found that full-length use of MA sensors is possible with OS not lower than Android 5. The survey also reveals that users of gadgets with Android OS have new versions of 5 and above (99%); it creates the best opportunities for using MA (Fig. 2b).

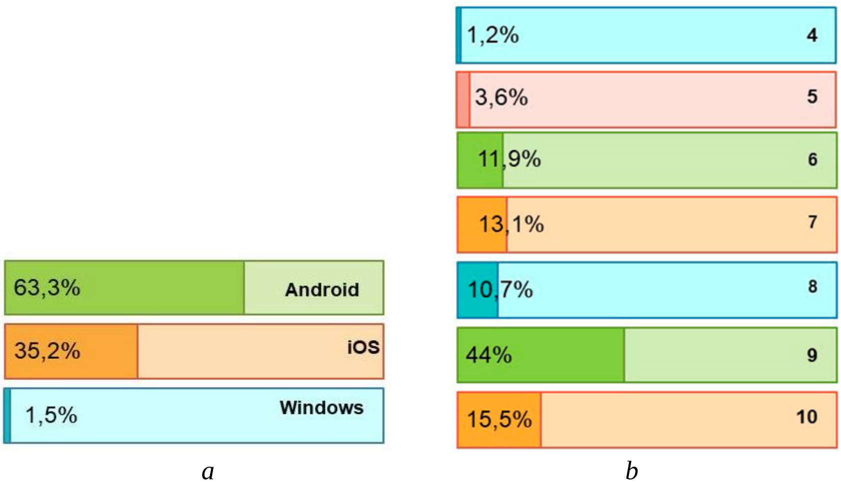


Fig. 2. Distribution of answers to the questions: OS type (*a*); Android version (*b*)

The same survey has showed that the vast majority of respondents were aware of the presence of sensors (Fig. 3a), (especially popular GPS navigation applications) but did not use them in their educational activities (Fig. 3b) and are eager to learn more about these opportunities (Fig. 3c).

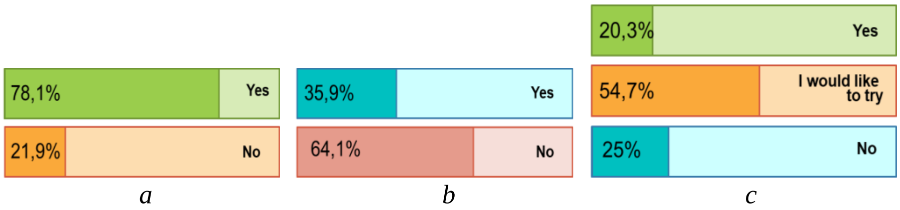


Fig. 3. Sensor usage data

The review and testing of the most promising MA sensors that can be installed and run on the studied smartphones allowed distinguishing the Physics Toolbox Sensor Suite, Phyphox and the Scientific Journal (Google). Note that additional selection criteria were free of charge and cross-platform.

These MA automatically detect the presence of sensitive elements and have the ability to store and transmit data in a format that uses mathematical tables (for example, Excel spreadsheets). Note that the use of each of these applications is determined by the task. For example, the MA *Physics Toolbox* records and transmits data to other digital devices but the analytical capabilities of this application are insufficient.

MA *Phyphox* contains ready-made methodological solutions for practical work and is an open platform with the possibility to add individual techniques. A teacher can arrange a new experiment with the appropriate processing and presentation of measurements. In addition, the app lets share the smartphone screen with another device, for example, a desktop computer with a video projector, and control the smartphone through a connected device.

The *Science Journal* (Google) MA cannot always identify sensitive elements but allows creating a full-length study with comments and illustrations and saving it to Google Drive.

Methods of carrying out educational research using a smartphone.
Let us consider one of the options for doing the lab «Determination of free fall acceleration using a simple pendulum» based on the use of MA Physics Toolbox Suite and Excel spreadsheets. Such a study can be carried out using two smartphone sensors - a proximity sensor and an accelerometer. In this case the task can be expanded comparably with its «classical» variant: calculation of the value of free fall acceleration by the average value of the pendulum oscillation period measured with the proximity sensor and comparison it with the accelerometer data.

To achieve this aim, in addition to the smartphone attached to the stand, we use a bifilar thread pendulum, ruler, and caliper (Fig. 4). The technological map of the work consists of three main parts: measurement of physics quantities, data analysis, and their presentation.

Measurement of free-fall acceleration. The support is mounted on a horizontal surface and secures the bifilar suspension for the pendulum. Measure the diameter of the ball of the pendulum (the ball should have a good reflectivity of light color) then hang up and, using a ruler, measure the shortest distance from the point of the ball attachment to the horizontal bar of the bifilar suspension. In the MA Physics Toolbox Suite, select the Proximeter and check the proximity sensor response to moving obstacles (most smartphones perceive obstacles less than 8 cm).

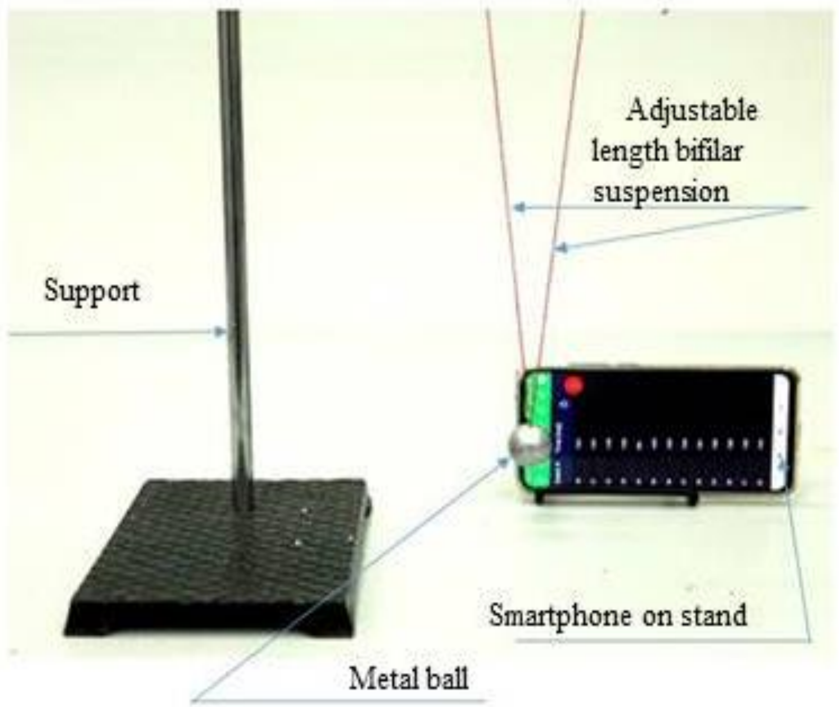
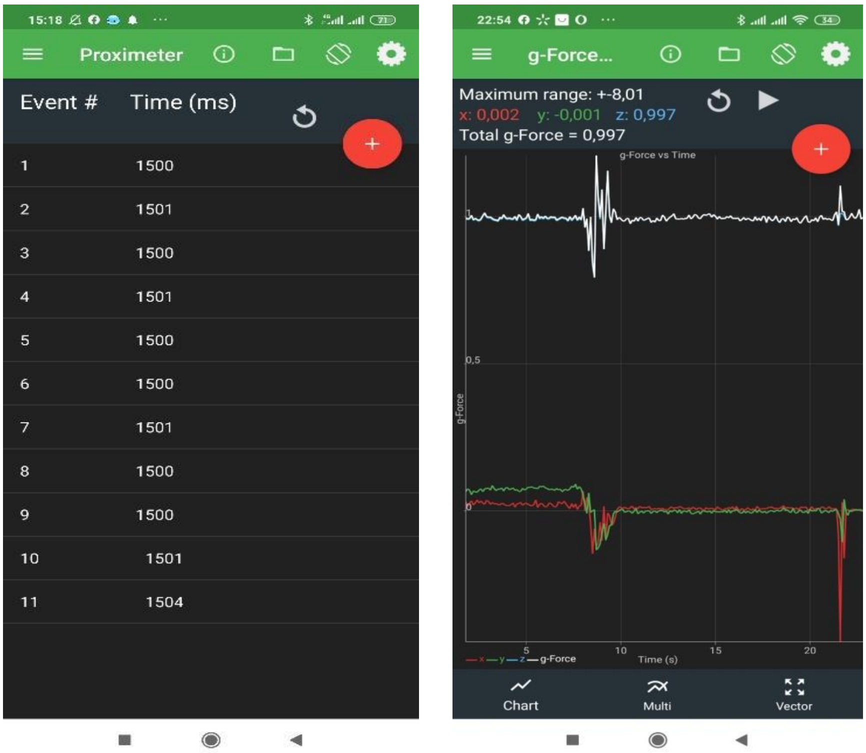


Fig. 4. Installation for measuring T, s using simple pendulum

Place the smartphone on the stand and adjust its position so that the pendulum ball at greatest deviation will trigger the proximeter (the angle of deviation should be small). Select the Pendulum function and enable data recording. Stop recording after measuring a time of 10 – 15 oscillations and turn the results in a convenient. csv format. Next, switch to the g-Force Meter accelerometer tab., place the phone on a horizontal surface, read and record the free fall acceleration along the vertical axis (Fig. 5).

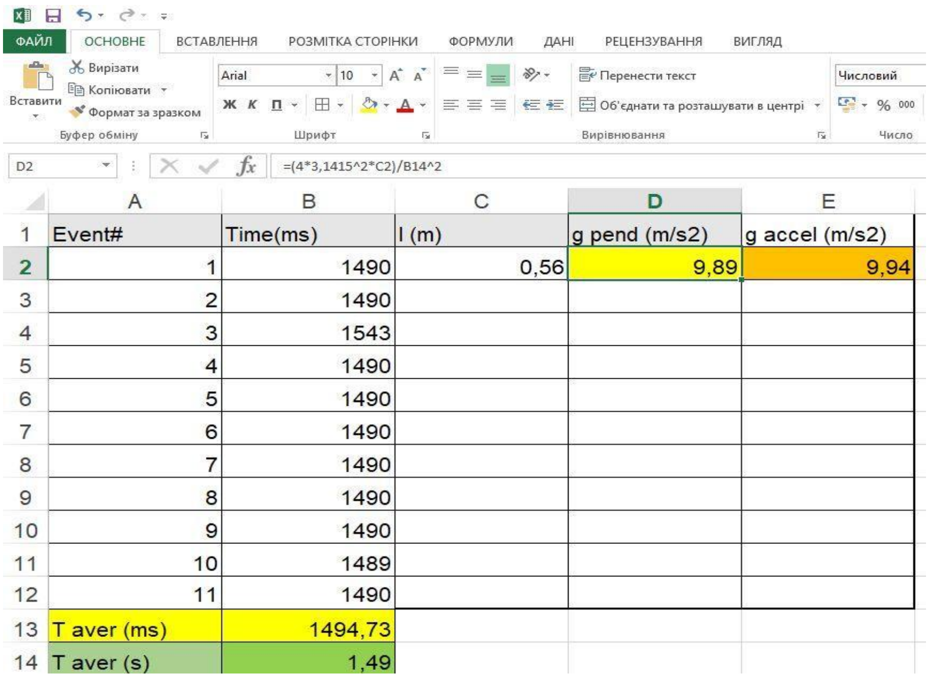


a *b*

Fig. 5. Screenshot of the *Android Physics Toolbox Suite* app with tools: *Proximeter* (a), g-*Force Meter* (b)

Experiment Data Analysis. Download the oscillations period (T, ms) data file and open it in Excel. Using the tools of mathematical tables, get the average period and express it in seconds. Calculate the length of the pendulum by measuring the shortest distance from the point of attachment of the ball to the crossbar of the bifilar and adding the radius of the ball and record it in the tables. Using mathematical tables, the values of $g_{pend}, m/s^2$ obtained by the proximity sensor are calculated; then the acceleration values of free fall $g_{accel}, m/s^2$ obtained by the accelerometer are recorded in the tables (Fig. 6). Compare the values obtained and make conclusion.

Study Development. To improve the accuracy of the experiment, we can repeat the measurements of the oscillation period at different lengths that the oscillation period of the pendulum should be within 0.5 s to 1.5 s.



	A	B	C	D	E
1	Event#	Time(ms)	l (m)	g pend (m/s2)	g accel (m/s2)
2	1	1490	0,56	9,89	9,94
3	2	1490			
4	3	1543			
5	4	1490			
6	5	1490			
7	6	1490			
8	7	1490			
9	8	1490			
10	9	1490			
11	10	1489			
12	11	1490			
13	T aver (ms)	1494,73			
14	T aver (s)	1,49			

Fig. 6. The experiment data Table *Excel*

5 Conclusions

Our analysis of modern MA for physics education showed that they can be divided into four groups: MA-manuals, MA for control and evaluation of knowledge and skills, MA-virtual laboratories, and MA sensors. These MA can help to reach a new level of experiments performance not only through access to virtual, remote experiments but also by providing real measuring tools for educational research.

Analysis of smartphones of different generations and operating systems has shown that nowadays the smartphone can be actively used as a measuring and analytical tool for the natural sciences study. A comparative analysis of the hardware and operating parts of teachers' and students' smartphones revealed that today most of them use smartphones running the latest-generation Android OS and contain a large number of sensors. However, the questionnaire showed the lack of targeted use of MA sensors for experiments. Thus, the crucial need for the formation of the following teachers' skills was identified, namely:

- be able to investigate sensors of MA and form groups of learners (on the basis of the analysis of available sensitive elements in their smartphones);
- be able to explain to students at what stage and how to use effectively the capabilities of MA sensors;

– be able to combine the possibilities of measuring instruments of the smartphone with other types of MA (Fig. 1).

It is also important to expand the proposed techniques by studying the structure and physics principles of sensors.

Obviously, application of smartphones reinforces the competence of teachers in using MA to solve education tasks. The method of measuring and processing data with the use of MA sensors of smartphones is one of the key examples of the effectiveness of m-learning. Such technology significantly changes the education process. It removes the routine stages, rationalizes and facilitates the process of data analysis during educational physics experiment. Evidently, it is the best way to complement traditional approaches to natural sciences study.

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