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Smartphone and teamwork as a methodological tool for teaching and learning physics

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Abstract. This research is based on the usefulness of mobile phones as a tool for students to learn about uniform rectilinear motion in vertical free fall, based on experimental practice. To evaluate whether these mobile devices allow better learning on the subject, a pre-test/post-test design was carried out with 43 students participating in the 9th grade in natural sciences. McNemar and Stuart-Maxwell non-parametric tests were applied. The proposal on the experimental practice gave satisfactory results when comparing the pre-test and post-test, in the analysis of the particular and global form of the answers.

1. Introduction

According to Vazquez-Alonso, *et al.* [1], considering globalization, it leads to educate the citizen with responsibility emphasizing that all countries must have universal language, artistic literacy, and scientific literacy as a basis. Although the interests of students in the last two decades have decreased in technology and science, specifically in physics and mathematics [2], consequently it can affect research, which is necessary for innovation in a high percentage of countries belonging to Europe [3].

It is worth emphasizing the manifesto of several authors with respect to the favorability of students in childhood with respect to science, which decreases with advancing age; this is evidenced in secondary school in the upper grades with not very encouraging results in technical scientific studies, particularly in chemistry, mathematics, and physics [4-8]. There are several causes for the lack of interest of students in this field; some are focused on the lack of innovation in strategies that reflect the importance and dynamics of sciences well used in favor of society, and that teachers encourage them to solve problems that arise in the environment [1,2,9].

In the same order [10], consider that the study of kinematics is used in a complex way, with its conceptualizations that are opposed to the students' conceptions, making the learning process difficult. The lack of innovation during studies, from the beginning to the introduction to the first semesters of engineering. [11,12]. Based on some difficulties related to kinematics, the following are described: Considering force as the cause of movement, considering that the bigger and heavier an object is and the more it weighs the faster it will fall, not having clear signs of acceleration, confusing the concept of acceleration with that of velocity, among others [4].

Science, technology, engineering, and mathematics (STEM) is a teaching methodology that aims to teach science, technology, engineering, and mathematics in a new and joint way through problem solving in general using technological support [13]. This strategy as any new and innovative teaching and learning methodology seeks to be motivating for students and facilitates the introduction of the



development of science as a method of exploration through questions that lead to hypotheses, which require the search for validation and dissemination of these results [14-17].

Indeed, methods that facilitate teaching, promoting the interest and motivation of participants in the study of science [18], leading them to apply the knowledge acquired in the development and progress of their environment, methods that allow research based on their own interests, improve the results in the study of science [18,19], as well as kinematics and their teaching and learning processes [6,11,20,21], lead to proposals that incorporate current issues in secondary education, related to science-technology-society and physics [6,11,20,21] based on practical experimental experiences.

In the last two decades, smartphones and/or tablets have been included as an alternative for practical experiences in laboratories and classrooms to complement and strengthen concepts, considering the availability of these devices to students in their daily lives. To encourage interest in physics and chemistry, teachers propose practical experiences using sensors such as the accelerometer, gyroscope, light sensor, among others, of smartphones and tablets as tools [22].

Consequently, the participants in these experiences understand the importance of what they have learned to put it into practice in their daily lives [17], inducing them to motivate themselves in learning [23]. Although we find a wide range of bibliographies with proposals for experimental practices based on the use of smartphones or tablets as measurement materials in physics, so far there has been no verification of the effectiveness of these devices in students' learning of physics [2,22].

Therefore, the objective of the experience has been to verify if the use of smartphones helps the student to better understand the concepts related to rectilinear motion in vertical free fall. To this end, practical didactic sequences and a pre-test/post-test design were designed to assess to what extent students' learning about this concept was improved.

2. Experimental teaching strategy

Based on the proposals of [24-28], the experimental practice on free fall movement was constructed, based on the use of the mobile phone using a free application for the Android operating system, which allows the data recorded in the device's accelerometer to be introduced and known using the smartphone's internal sensors. Likewise, the linear accelerometer and G-force functions will be used from the application in the experimental practice, highlighting that the accuracy and precision of the sensors depend on the software of the mobile phone. Therefore, five activities were designed for the proposal, which are carried out in two sessions with a time of one hour each. The proposed activities are described in the following paragraphs.

2.1. Activity 1

Hypothesis formulation regarding body mass and free fall of an object; based on a playful activity called bungee jumping, students are introduced to the experimental practice of free fall and the following questions are asked: Is the acceleration in free fall constant or variable; is free fall a uniformly accelerated movement; if the object has a greater mass, does it accelerate more when falling?

2.2. Activity 2

Knowledge of the use of the accelerometer of the mobile phone; the experimental practice is based on the use of the mobile phone accelerometer included in the physics toolbox sensor suite application for data recording. The students identify how they should drop the device by identifying the X, Y and Z axes of the mobile phone [23]. It is about observing and pointing on the axis that marks the value of acceleration of gravity (g) of an object under ideal conditions which is $g=9.8 \text{ m/s}^2$.

2.3. Activity 3

Study of free fall acceleration. In this activity the student is facilitated to use the function of the "linear accelerometer" by recording the data, the mobile phone is dropped from a height of 1.5 meters. The application displays the graph on the mobile screen when the mobile starts to descend and senses a

weightlessness-like effect that causes the mobile application to detect the earth's gravitational force ($\approx 9.8 \text{ m/s}^2$).

2.4. Activity 4

Influence of mass on free fall. This activity develops the conceptualization of the direct relationship between the mass of a body in free fall and the speed it reaches [29]. Initially, the "linear accelerometer" function of the application is applied, the mobile phone alone is dropped three times, then two mobile phones of the same characteristics are dropped three times from 1.5 meters and the data is recorded. Based on the measurements taken, the average drop time for each of the systems is averaged: Mobile phone 1 (with mass m) and the 2 mobile phones (approximately with mass $2m$). The acceleration of a body in free fall is due only to the earth's gravity, disregarding air resistance.

2.5. Activity 5

Socialization of results. At the end of the experimental practice, the students socialize the results obtained from the activities carried out and, based on these, are guided to give their answers to the following questions: what is acceleration like; what value does the acceleration of an object have when falling freely; is there any difference between the time that a mobile phone registers when reaching the ground and the time that two mobile phones register together; is there any variation in speed when the phone is falling; does what you have learnt have any applicability; is there any variation in speed when the phone is falling? The objective is socialization and input from students, stimulating practical applications of free fall and its relation to bungee jumping.

3. Methodology

A quantitative research approach was applied at a correlational level, which consisted of two measurements (pre-test/post-test) including the physics laboratory between both tests. The population consisted of ninth grade students from an educational institution in the municipality of Sardinata, in the region of Catatumbo, Colombia.

A probability sample was selected using the simple random sampling technique by initially determining the sample size calculated by means of Equation (1) with the following parameters: population size ($N = 89$), expected probability of success in the test that contributes to the maximum sample size ($P = 0.5$), estimation error of 3% ($e = 0.03$) and a confidence level of 95% (equivalent to $Z = 1.96$) with a significance level of 5% ($\alpha = 0.05$). An optimal sample size was then obtained using Equation (2) and arrived at a total of 43 students.

$$n_1 = \frac{N \cdot Z^2 \cdot \frac{\alpha}{2} \cdot P \cdot (1-P)}{e^2 \cdot (N-1) + Z^2 \cdot \frac{\alpha}{2} \cdot P \cdot (1-P)}, \quad (1)$$

$$n_0 = \frac{n_1}{1 + \frac{n_1}{N}}. \quad (2)$$

Regarding the demographic characteristics of the students, it was identified that 53.5% were male, with ages between 12 years old and 17 years old, which allowed us to determine that 14.9 years old corresponds to their average age. However, on the experimental practice of the free-fall movement, an evaluation was carried out with a pre-test/post-test design to check the effectiveness in improving the students' learning; this evaluation consisted of a questionnaire based on the proposal validated by [30] for the modification of the force concepts inventory.

The questionnaire is composed of six single-choice questions on a Likert scale accompanied by a space to argue your answer, distributed as follows: question 1 and question 2 are related to alternative ideas, question 3 and question 4 are based on concepts, question 5 is related to the use of methods acquired in experience, and question 6 is based on applications of free fall in everyday life known to the student; regarding the reliability of the questionnaire used, it was possible to verify that a

Cronbach's Alpha coefficient of 0.72 was obtained, which according to [31] is evidence of good internal consistency, *i.e.*, that the instrument measures what it is expected to measure. The pedagogical intervention lasted for two weeks between the two applications of the questionnaire. The collected data were processed using commercially available statistical software to verify the possible existence of differences between the two measurements.

4. Results and discussion

In order to establish differences between the score obtained by each student in both measurements, the following rubric was used: if the argumentation and processes carried out support the correct answer, three points were assigned; in the case of incomplete processes, but reaching the correct answer, two points; one point if the answer is correct but not justified by any process; and zero points if the answer is incorrect. In this way in each measurement the student's score can vary between zero and eighteen points. Table 1 shows the basic descriptive statistics associated with each measure.

Table 1. Descriptive statistics.

	Minimum	Maximum	Mean	Deviation
Total pre-test	6	14	9.30	1.753
Total post-test	12	18	16.44	1.385

When comparing the total mean scores of both measurements, it was possible to determine that in the post-test the results exceeded those obtained in the pre-test, accompanied by a smaller dispersion in them, that is, the scores in the post-test were in a smaller range than those in the pre-test. These results would suggest that the pedagogical intervention yielded significant results in the understanding of the topic under study.

Before validating the hypothesis system mentioned in Equation (3), the normality of the data was checked using the Shapiro-Wilk test at 5% significance level. The non-parametric test of ranges with Wilcoxon sign is applied, which yields a test statistic of -5.712 corresponding to a probability of 0.015, which is less than 5%, then it is concluded that there is not enough evidence to accept the null hypothesis or what is equivalent to say that from these results it could be verified that there are statistically significant differences between the total means of both measurements, obtaining a higher average in the post-test.

$$\begin{cases} \text{Null hypothesis } H_0: \mu_{\text{post-test}} \leq \mu_{\text{pre-test}} \cong \mu_{\text{post-test}} - \mu_{\text{pre-test}} \leq 0 \\ \text{Alternative hypothesis } H_a: \mu_{\text{post-test}} > \mu_{\text{pre-test}} \cong \mu_{\text{post-test}} - \mu_{\text{pre-test}} > 0 \end{cases} \quad (3)$$

where H_0 is the null hypothesis, H_a is the alternative hypothesis, $\mu_{\text{post-test}}$ is the average post-test, and $\mu_{\text{pre-test}}$ is the average pre-test. Table 2 shows the calculation of the effector size [32], where a significant medium effect is obtained with a value of 0.4460 and a power of 1.000.

Table 2. Statistical significance and effect size.

	Mean	Standard deviation	p-value<0.05	Size of the effect
Pre-test	9.30	1.753	Statistically significant difference	0.4460 Medium
Post-test	16.44	1.385		

On the other hand, Table 3 shows the percentages of correct, partially correct, and incorrect answers obtained by the students in the pre-test and post-test. It can also be seen that the range of percentages of incorrect answers between the pre-test and the post-test decreased from 83.7% and 51.2% to 11.6% and 20.9%, respectively, for the questions on conceptions of free fall (items 1 and 2). However, for the questions on concepts based on this type of movement (items 3 and 4), the percentage of incorrect answers decreased from 65.1% to 9.3% and from 58.1% to 2.3%, in their order, in contrast to the percentage of correct answers which increased from 11.6% and 14.0% to

83.7% and 90.7%, respectively. Turning to the questions on how to apply what was learned in the experimental practice (item 5) or the applicability of free fall in everyday life (item 6), it is relevant the decrease in the percentage of incorrect answers in the post-test from 48.8% to 7.0% and from 65.1% to 4.7%, in their order, in contrast to the increase in the percentage of correct answers, which were between 51.1% and 74.4%, respectively.

Table 3. Percentage of responses to each pre-test question and post-test question.

Question	Pre-test						Post-test					
	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6
Correct	14.0	46.5	11.6	14.0	23.3	11.6	88.4	79.1	83.7	90.7	74.4	86.0
Partially correct	0.0	0.0	18.6	23.3	27.9	18.6	0.0	0.0	7.0	7.0	16.3	9.3
Incorrect	83.7	51.2	65.1	58.1	48.8	65.1	11.6	20.9	9.3	2.3	7.0	4.7

Table 4 shows the results derived from the non-parametric Stuart-Maxwell test that was used to verify the existence of significant differences between the two item scores. Also, the effect size of the pedagogical intervention on the post-test results is determined. According to the results of Table 4, it is evidenced that the use of mobile phones confirms the significant effectiveness of the experimental practice, leading to the strengthening of alternative conceptions, in the application of methods, concepts of physics, knowledge of applications of free fall movement in everyday life, among others. Likewise, effect sizes and large potency were obtained in all the questions [32].

Table 4. P-value, effect size, and potency for each question of the pre-test/post-test questionnaire.

Question	p-value<0.05	Size of the effect	Potency
1	There is a statistically significant difference	2.2025	Great
2	There is a statistically significant difference	0.6989	Great
3	There is a statistically significant difference	1.9914	Great
4	There is a statistically significant difference	2.1479	Great
5	There is a statistically significant difference	1.2150	Great
6	There is a statistically significant difference	2.2309	Great

The implementation of new technologies such as mobile phones for experimental data collection, as well as different technological programs, and new integrative methodologies such as STEM contributed to the enthusiasm and motivation of students in the educational process by raising the interrelation of mathematical concepts and their applicability in physics and facilitating the study of science and its relationships, in partial agreement with [17], who in their project used video to facilitate reading comprehension and in agreement with [33], who implemented both STEM methodology and smartphones.

Smartphones have been of great interest for the teaching and learning process of Physics, and for this reason we have found in recent years proposals to carry out practical experiences with these devices as a projection to improve the learning of students in this subject. Within this order of ideas, this research is based on the use of the mobile phone, for which an experimental practice has been designed directed in the uniformly accelerated rectilinear motion of free fall, to facilitate students' understanding of the alternative conceptions about this movement agreeing with [34], who implemented the same strategies.

As well as the implementation of attractive leading or trigger questions that seek to motivate students and help them feel involved in their own learning while facilitating the teaching-learning process, agreeing with [33], who also presented an attractive trigger question for their students and partially with what was suggested by [15], who suggest the need for teachers to start with interesting learning strategies for their students, and with [16], who propose to facilitate the change of students' beliefs towards mathematics by stimulating them with meaningful and entertaining learning.

Finally, as a synthesis, an experimental practice was designed, focused on the uniformly accelerated rectilinear movement of free fall that is based on the use of the mobile phone with the purpose of helping the student to better understand the concepts related to this movement. This shows that the use of digital devices is of great interest for the teaching-learning process of natural sciences, since they enhance the gain of active learning [35,36], which allows the integration of knowledge [37], especially in physics.

5. Conclusions

As results of the study, it can be concluded that this experience that relates smartphones with the practices of a physics laboratory, encourages students to use technology for educational purposes, which encourages their participation and motivation in the learning process, but it is to clarify that the use of smartphones by themselves is not a solution to the difficulties encountered in the development of laboratory practices. Therefore, the use of the smartphone as a didactic tool to work on a practical experience on the free fall movement has shown that the data obtained, through the action of the accelerometer, during the development of the practice are valid and reliable, allowing rediscover the physical laws involved.

The results show statistically significant differences, as well as a large effect size and power values within the general means of the pre-test/post-test questionnaire. The foregoing confirms that the use of the mobile phone in the experimental practice on the movement of free fall satisfies the objective of this research, which is aimed at facilitating the learning of this movement in students.

Finally, this work validates how a proposal on the use of smartphones in the teaching of Physics as a measuring instrument in practical experiences helps to improve student learning in this area. However, further research should be carried out in the development of proposals of this type integrated towards constructivist approaches and the evaluation of their effectiveness with larger samples of students and of different educational levels.

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