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The Use of Mobile Learning Resources to Enhance Physics Learning for Engineering Students: A Six Year Study*

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The use of mobile devices for learning purposes has increased in recent years, but there has been little effort to measure its impact on student outcomes. The goals of this work are: to quantify the impact of using mobile learning resources on academic performance and to know the student perception about these resources. Our hypothesis is that mobile learning resources have a positive effect on the learning processes. We evaluate the effectiveness of two mobile learning resources for engineering students regarding free body diagram and conservation of linear momentum. We gave pre and post-tests to experimental and control groups during a 6-year time span and analyzed the differences in the learning gains for both groups. We also gave perception questionnaires to our students about the use of mobile learning resources. With a sample of $N = 645$ students, we found that the experimental group obtained learning gains 7–10 points higher (on a 0–100 scale) than the control group. We found robust evidence regarding the effectiveness of our mobile learning resources through linear regressions ($p = 0.001$–0.053) and t-Student tests ($p = 0.002$–0.045). However, the observed effect size was only $ES = 0.28$. The student perception questionnaires indicate that students found the implementation of mobile learning resources to be very useful. Our results are indicative of a positive impact of the use of mobile learning resources to enhance student concept comprehension and problem-solving skills in undergraduate Physics courses.

Keywords: mobile learning; learning gains; student perception; physics; blended learning

1. Introduction

The use of mobile devices (smartphones, tablets, etc.) for educational purposes has increased exponentially worldwide, as new generation Z students are gradually entering the educational institutions and universities. Mobile technologies have definitively changed the way in which students learn and communicate [1–4]. The incorporation of multimedia mobile learning (mL) resources (e.g., videos, podcasts, games, etc.) into learning environments comes, then, as a natural tool to be implemented with the so-called digital-native students, who grew up surrounded by electronic devices containing strong visual and auditory stimuli [5–7]. As such, intensive work has been done in order to implement mL in education and training programs in diverse institutions and organizations. Important efforts to design appropriate environments and models of mL in educational institutions of diverse academic levels, ranging from preschool to university, and in different subject domains have been reported in the literature [8–12]. Accordingly, attention has been dedicated to defining suitable frameworks of reference for designing mL environments in order to promote effective student learning and interaction [13–15]. These learning environments use online multimedia resources provided by appropriate LMS platforms in order to allow interaction among instructors and learners and take advantage of Web 2.0 collaborative features [6, 16–18]. As such, mL environments allow instruction in both distance and blended learning models, for example through selected videos covering specific course topics, so that students can review and practice them at their convenience and at own pace [19, 20]. Another example is given by Nouri [21–22], whom provides a theoretical grounding of mathematical learning supported by mobile technology.

A major concern among researchers and educators has been the effectiveness of mL to promote appropriate and enhanced student performance. Most of these studies rely on the perceptions of students and educators regarding the benefits of mL, and most of them agree that the use of mL environments has a positive impact on student learning [8, 20, 23, 24]. On the other hand, other studies warn about possible negative outcomes or risks from the misuse of mL, especially when the devices cause students to become distracted during class time [6, 25, 26].

Due to the complexity involved in assessing the impact that mL environments may have on student performance, most studies have only covered limited timespans –typically only one academic term. While it would be highly desirable to extend these

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studies to larger time intervals [14, 19, 27], there has been little effort to do so. In one such case, however, Cochrane [17] conducted a study from 2006 to 2011 which identified six critical success factors for the implementation of mL through the Web 2.0. Prior to this, Cochrane [28] had also conducted a 6-year study in which 35 mL projects were implemented and evaluated over a variety of contexts in higher education and reported that not all mL projects were successful.

Other studies have focused on the characteristics needed to design appropriate online resources in order to engage and motivate students. In doing so, instructors expect these appealing resources to promote deeper and long-lasting student learning. In this respect, multimedia features such as videos, simulators and games have been incorporated as online resources [29–32].

In 2008, the *Tecnológico de Monterrey* launched its mobile learning model, which involved the widespread and systematic use of mobile devices to access mL resources, both with high-school and undergraduate college students. To build this model at an institutional level, it was necessary first to define the critical factors behind it, considering that it should foster student knowledge acquisition based on self-directed learning and a well-defined instructional design [33]. As part of this effort, the eLearning research group at *Campus Ciudad de México* designed a set of short videos for specific Mathematics and Physics topics for engineering students which were to be delivered as mL resources. The goals were: (a) to design high-quality engaging and motivating short videos and (b) to study their impact on student performance. Preliminary results were reported by [29, 30, 32, 34, 35].

Another example at a different educational level is the mL project "*Mati-Tec*", which was launched in 2011 by the Tecnológico de Monterrey and Fundación Telefónica. It was aimed to enhance the Mathematics and Spanish literacy of children in public elementary schools in Mexico. The process used to design the mL resources was reported by [36], and the results regarding the impact of the mL resources on the students' performance was reported by [37], who found a positive correlation between student performance and the use of mL resources.

Although the above-mentioned studies report that the use of mL resources may have a positive impact on student performance, we believe that this issue deserves further attention as a research question. Therefore, the research questions and contributions of this paper are: (a) to present and discuss the main elements behind the design and implementation of mL resources, and (b) to present a 6-year study (2009–2015) regarding the learning gains from the use of mL resources in selected undergraduate Physics courses for engineering students at the *Tecnológico de Monterrey, Campus Ciudad de México.* We also present results from a survey intended to measure students' perception of the usefulness of these mL resources for learning Physics concepts. Note that our 6-year study was focused on assessing the impact of specific mL resources. We did not attempt to build an integral mL environment for the Physics course using other device apps such as audio, video, photo, geo-localization systems or social networks. Some commercial mobile apps related to physics education include: WolframAlpha, Wolfram Physics, LearnSmart, SmartBook, iLearnPhysics, PhysDios, Particle Zoo, SimPhysics, and Science 360. General mobile apps for educational purposes include: Doceri, Socrative, Educreations, Explain Everything, Nearpod, Edpuzzle, and Elever.

This paper is organized as follows. In Section 2, the considerations followed in the design of the mL resources for Physics courses are presented. Section 3 describes the methodology used to implement and assess the impact of these mL resources on student outcomes for two Physics course topics: particle dynamics and linear momentum. The main results and discussion—including student learning gains, effect size estimations, linear regression analyses and student perception of the use of the mL resources—are presented in Section 4. Finally, the main conclusions and future work are summarized in Section 5.

2. Design of mobile learning resources

As mentioned above, the *Tecnológico de Monterrey* launched a general mobile learning (mL) initiative in 2008, which was aimed to implement a generalized use of mobile devices by students. The methodology and considerations used in the design of the mL resources for the Physics I (Introductory Classical Mechanics) course for engineering students was as follows:

(a) During the summer of 2008, the main relevant themes and concepts to be addressed with the mL resources were identified by a group of faculty professors of the Physics & Math Department. Later, both faculty and part-time professors helped to develop short videos for these main course themes.
(b) After a first implementation run in the fall of 2008, three of these mL resources for two key topics of the Physics I course were re-designed during the summer of 2009, taking into account feedback from both students and staff gathered after the first implementation run. The course

topics addressed by these three mL resources were *Particle Dynamics* (in particular, Free Body Diagram, one resource) and *Linear Momentum* (in particular, Conservation of Linear Momentum, two resources).

(c) Expert pedagogical advisers from the *Tecnológico de Monterrey* carefully reviewed the instructional design and learning objectives of these educational resources.

(d) The mL resources were designed as short videos suited to be displayed in mobile devices. Graphic designers carried out the aesthetic and graphic design of the mL resources, including quality considerations such as: (i) resource duration and time management (appropriate cognitive load); (ii) clarity of presented elements (easy to follow and understand); (iii) sound and relevant content (meaningful for the students) and (iv) adequate management of key audio and video elements (motivating and engaging).

(e) The resulting mL resources were self-contained; that is, they contained: (i) an induction and a section for goal definition (framing); (ii) a brief theoretical framework section (theory); (iii) a demonstrative section (illustrated examples), and (iv) an evaluation section which challenged students about what they had just learned.

Overall, the mobile educational resources were produced under three main considerations: (a) that the content design integrated the course learning objectives; (b) that the educational resources accomplished quality objectives via their deployment through mobile devices, and (c) that the structure of content presentation generated a variety of stimuli, so as to motivate the student and enhance learning.

2.1 Particle dynamics resource

The Particle Dynamics mL resource deals with the concept of Free Body Diagram and the application of Newton's laws of dynamics (hereafter, FBD mL resource). It is a 5-minute video with the following learning objectives: (a) the student is able to recognize the forces applied to a system and build the corresponding FBD, (b) the student is able to decompose the forces acting upon a system in terms of their scalar components, and (c) the student is able to apply Newton's 2nd law equations of motion to the corresponding system.

In particular, the video explains the detailed procedure to correctly build a FBD of a block on a rugged incline that is being acted upon by a horizontal force (a black and white screen-capture of the video is shown in Fig. 1). The forces acting on the block are: (a) the applied external force, (b) the weight, (c) the normal force and (d) the friction force. These forces are drawn one by one throughout the video. It then shows how to break these forces down into their Cartesian components along an *x*-*y* coordinate system parallel to and up the incline. Then, Newton's 2nd law equations are written down for this particular coordinate system. For the sake of closure and evaluation, at the end of the video, the student is asked to draw a FBD and write down the corresponding Newton's 2nd law equations for a similar system as that which was explained in the video.

2.2 Conservation of linear momentum resources

There are two mL resources designed to address Conservation of Linear Momentum (hereafter CLM), another of the main topics of the Physics I course. The main learning objective of these resources is for the students to understand the concept of linear momentum and to be able to recognize real-life situations in which linear momentum of an isolated system is conserved. Two short videos were designed for this topic.

The first mL resource is a 6-minute video that presents a summary of the main concepts of this topic. It also reviews examples where linear momentum is conserved, as the one shown in Fig. 2, where a person walks on a horizontal board lying on a frictionless icy surface. At the end of the video, the student is asked to answer some review questions about the concepts presented.

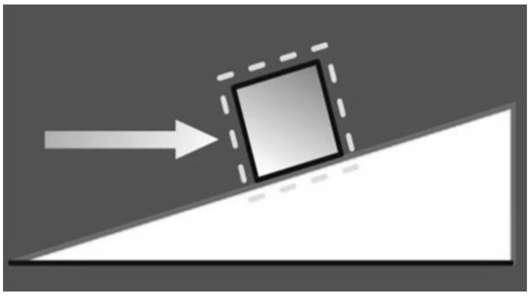


Fig. 1. Snapshot of the FBD mL resource (in Black & Withe) showing a block on an incline being acted upon by an external force.

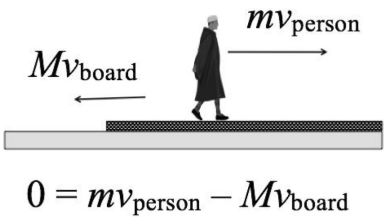


Fig. 2. Person walking on a board over an icy surface. The linear momentum of the person (mv_{person}) to the right is balanced by the linear momentum of the board (Mv_{board}) to the left. Since the whole system (person + board) is isolated, the total linear momentum is conserved.

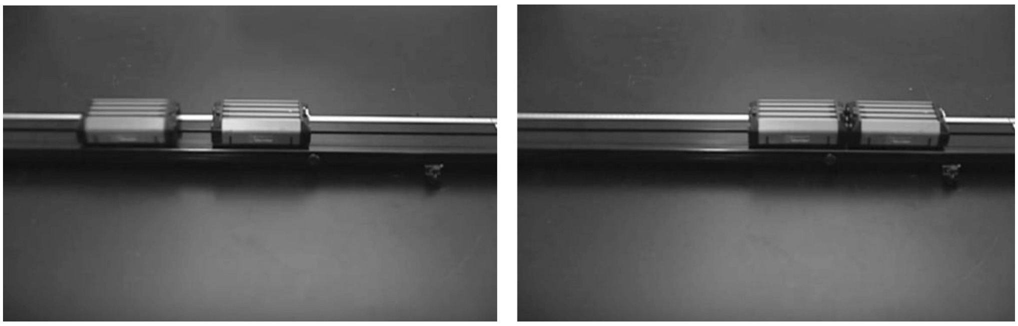


Fig. 3. Two stills adapted from our CLM mL resource showing a total inelastic collision between two carts of the same mass recorded in the lab, before (left) and after (right) the collision.

The second mL resource is a 5-minute video showing a series of collisions in one dimension between two small carts running over a horizontal frictionless air-track. The carts undergo three different types of collisions: (a) an elastic collision between two carts of the same mass, (b) an elastic collision between two carts with different masses (in a 2:1 proportion), and (c) an inelastic collision between two carts of the same mass.

In the video, the students are asked to perform the three types of collisions mentioned above in the Physics laboratory. They have to measure the carts' masses and velocities *before* and *after* the collision using electronic sensors in order to quantitatively determine whether linear momentum and kinetic energy are conserved. At the end of the video, the students are challenged with review questions about these topics. Two black and white stills from the video showing a total inelastic collision between two carts of the same mass are shown in Fig. 3.

The CLM mL resources were later redesigned in order to make them even more attractive and motivating for the students, by incorporating audio and visual design elements based on cognitive theory of multimedia learning [32]. Nevertheless, in order to preserve the same conditions throughout the present study, the original CLM mL resources described in this work were maintained.

3. Implementation methodology

3.1 Experimental and control groups

We implemented a pre-test/post-test methodology to experimental and control groups in order to measure the impact the use of the mL resources might have on student performance with respect to the two above-mentioned Physics topics (FBD and CLM). We measured the impact of the FBD mL resource from the August–December 2009 semester to the January–May 2015 semester. For the CLM mL resources, the time interval was from August–December 2009 to January–May 2011. The results for the *redesigned* CLM mL resources from August–December 2011 to January–May 2015 will be published separately.

Each semester we randomly chose the experimental and control groups. We also made sure that the professors participating in the study (two of the authors) had both experimental and control groups during the same semester, so as to control as much as possible the *professor-variable* in our analysis. The students of the experimental group were given access to the mL resources using their mobile devices (either a smartphone or a tablet) for about two weeks. On the other hand, the students of the control group *did not* have access to the mL resources, but rather were given similar content and instructions in a written, conventional fashion. During this period of time, each professor continued lecturing his classes as usual without any distinction between the groups.

For the FBD mL resource, the sample for the experimental group was $N_E = 253$ students while for the control group it was $N_C = 170$ students. For the CLM resource, we had $N_E = 116$ students and $N_C = 106$ students, respectively. It is worth mentioning that we cleaned our database out for "misclassified students" (less than 2%), who were originally assigned to the experimental groups but admitted later that they had not used the videos.

3.2 Pre-test and post-test design

For each topic (FBD and CLM), we designed a pre-test and a post-test that were basically the same format in each case and were carefully designed to assess the fulfillment of the learning objectives of each mL resource. The pre-test was given to the entire sample (experimental + control) *before* the experimental group had access to the mL resources. After the experimental students had access to the mL resources, the post-test was given to the entire sample. The pre and post-tests allowed us to calculate and compare the *learning gain* of the experimental and control groups, as explained below.

The pre-test and post-test for the FBD mL resource asked the students (a) to choose the correct FDB from 4 different given options representing the forces acting on a block that is sliding down on a rugged incline, (b) to draw the FBD of a block on a rugged incline acted upon by an external horizontal force, and (c) to write the corresponding Newton's 2nd law equations of motion.

Similarly, the pre-test and post-test for the CLM mL resources contained 5 multiple choice questions designed to measure student comprehension of (a) the definition of linear momentum, (b) the characteristics of elastic and inelastic collisions and (c) the conservation of linear momentum in one dimension.

The pre-test and post-test were graded using a well-defined rubric for each mL resource on a 0–100 scale, and students were given approximately 20 minutes to answer each test in the classroom.

3.3 Student learning gains

In order to proceed with the data analysis, we define the following variables for the experimental and control groups: the average *pre-test* grade: $\langle Pre \rangle = \frac{1}{N}\Sigma(Pre_i)$, where Pre_i is the pre-test grade of student *i*; and the average *post-test* grade: $\langle Post \rangle = \frac{1}{N}\Sigma(Post_i)$, where $Post_i$ is the post-test grade of student *i*. We also define the *student* learning gain: $G_i = (Post_i - Pre_i)$; the *group* learning gain: $G = \langle Post \rangle - \langle Pre \rangle$; the student *relative* learning gain: $g_i = \frac{(Post_i - Pre_i)}{(100 - Pre_i)}$; and the group *relative* learning gain (after Hake [38]):

$$g = \frac{\langle Post \rangle - \langle Pre \rangle}{100 - \langle Pre \rangle} = \frac{G}{100 - \langle Pre \rangle}. \qquad (1)$$

The relative learning gain for a given student is a measure of the actual gain that the student achieved $(Post_i - Pre_i)$ with respect to the maximum gain that he/she could have obtained ($100 - Pre_i$). The group relative learning gain has a similar meaning but refers to the whole group.

In Section 4.1 below, we present a detailed analysis of the different gains both for the experimental and control groups for the FBD and CLM topics for each semester, covering a 6-year time span.

3.4 Student perception questionnaire regarding mL resources

A questionnaire was designed in order to evaluate students' perception of the usefulness of the mL resources in supporting their learning. To test the temporal stability of such perceptions, the questionnaire was first given in 2009–2010 and again in 2015. The total number of students participating in the survey was $N_Q = 203$.

The questions included in the questionnaire were as follows: The contents and activities included in the mL resources (a) helped me to improve my understanding of the specific concepts presented about the topic (either FBD or CLM); (b) helped me to improve my problem-solving skills; (c) motivated me to study the course topics on my own, and (d) Overall, I consider that mL resources are useful for learning Physics concepts.

A 5-step Likert scale was used to evaluate each question, ranging from total agreement to total disagreement. Additionally, students were asked to suggest other types of activities that could be implemented as mL resources in their courses. The results obtained from the perception questionnaire are presented in Section 4.8 below.

4. Results and discussion

4.1 Student learning gains

We summarize our main results as grouped data in Table 1 for the FBD mL resource and in Table 2 for the CLM mL resources. In Table 1, we indicate the semester (AD = August-December, JM = January-May) along with the corresponding year and a capital letter indicating different sections within that semester. We also indicate the number of students *N*, the average section pre-test $\langle Pre \rangle$, the average section post-test $\langle Post \rangle$ (both in a 1–100 scale), the section learning gain *G*, and the section relative learning gain *g*, as defined above. In the last column of Table 1, we also list the number of those few students with negative learning gains (G_i) in a given semester. We found relatively high standard deviations of about 20 both for $\langle Pre \rangle$ and $\langle Post \rangle$. In the last row labeled TOTAL, we give the total number of students, the weighted averages of $\langle Pre \rangle$, $\langle Post \rangle$, *G* and *g*, and the total number of students with $G_i < 0$. We present the results obtained with the experimental group (upper part of the table) and with the control group (lower part of the table). Table 2 is similar to Table 1 but contains the results of the CLM mL resources.

As can be seen in Tables 1 and 2, the average pre-test scores for the experimental and control groups are similar, as expected, since the selection of each group was random at the beginning of the semester. This result indicates that both the experimental and control groups started with a similar level of knowledge of the considered topics *before* we initiated this study.

In Fig. 4a and b, we show the distribution of the student leaning gains G_i binned in intervals of 20 units for the FBD and CLM mL resources respectively. As can be seen from these figures, the learning gains distribution for the experimental group leans more towards the higher values as compared to those of the control group. This trend is more

Table 1. Average pre-test, post-test and group learning gains for experimental and control groups for the FBD mL resource

Term-Section	***N***	**<*Pre-test*>**	**<*Post-test*>**	***G***	***g***	**$G_i < 0$**
Experimental						
AD2009-A	29	30	45	15	0.22	2
JM2010-A	12	33	57	24	0.35	0
JM2010-B	18	43	77	34	0.59	0
AD2010-A	12	34	60	26	0.39	1
AD2010-B	18	43	53	10	0.17	5
JM2011-A	12	40	61	21	0.35	0
JM2011-B	19	32	71	39	0.58	0
AD2011-A	24	26	51	25	0.35	0
AD2013-A	26	28	55	27	0.38	4
JM2014-A	15	49	62	13	0.25	3
JM2014-B	16	25	61	36	0.47	0
JM2015-A	30	28	66	38	0.53	0
JM2015-B	22	48	69	21	0.49	0
TOTAL	253	34	60	26	**0.39**	15
Control						
AD2009-A	28	22	38	16	0.21	3
AD2009-B	17	33	42	9	0.13	5
JM2010-A	19	31	44	13	0.19	2
AD2010-A	13	36	55	19	0.30	2
AD2011-A	9	41	56	15	0.25	3
AD2012-A	14	32	38	6	0.10	3
AD2013-A	21	27	55	28	0.39	5
JM2014-A	17	36	54	18	0.28	1
JM2015-A	13	31	67	36	0.52	4
JM2015-B	19	40	70	30	0.50	2
TOTAL	170	32	51	19	**0.29**	30

Table 2. Average pre-test, post-test and group learning gains for experimental and control groups for the CLM mL resources

Term-Section	***N***	**<*Pre-test*>**	**<*Post-test*>**	***G***	***g***	**$G_i < 0$**
Experimental						
AD2009-A	21	36	65	29	0.45	2
JM2010-A	19	44	67	23	0.41	1
JM2010-B	15	42	62	20	0.34	0
AD2010-A	13	35	62	27	0.42	2
AD2010-B	28	25	51	26	0.35	2
JM2011-A	20	32	59	27	0.40	3
TOTAL	116	35	60	26	**0.39**	10
Control						
AD2009-A	15	51	65	14	0.28	3
JM2010-A	18	41	59	18	0.31	4
JM2010-B	29	49	61	12	0.24	7
AD2010-A	17	21	44	23	0.29	2
AD2010-A	18	35	52	17	0.26	2
JM2011-A	9	40	49	9	0.15	1
TOTAL	106	40	56	16	**0.26**	19

evident for the FBD than for the CLM mL resource. It can also be seen that in both cases, the number of negative leaning gains is smaller for the experimental group than for the control group.

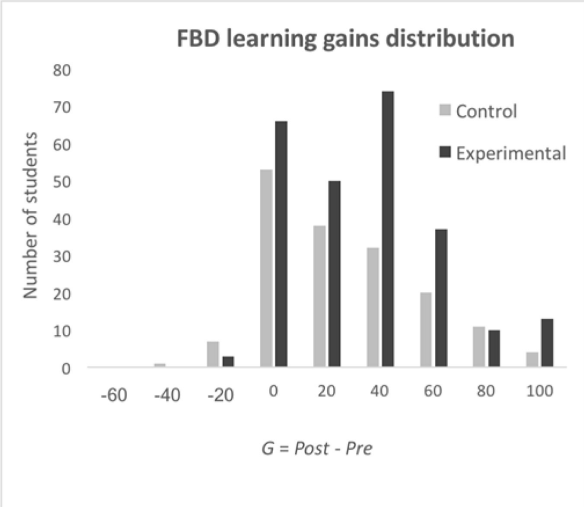
In addition to the distribution of learning gains shown (Fig. 4a and b), we analyzed the difference between experimental and control groups using four different complementing approaches: (a) effect size, (b) comparison of means using *t*-Student statistics, (c) *Hake diagrams* and (d) multiple linear regression. Our results are as follows.

4.2 Effect size

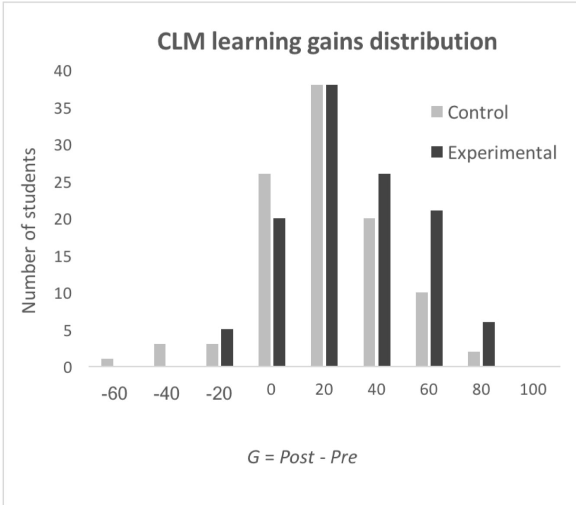
The effect size (*ES*) measures the magnitude of the difference between the experimental and control means in terms of the number of standard deviations [39–40]. We computed the *ES* of the group relative learning gain as

$$ES = \frac{\langle g \rangle_E - \langle g \rangle_C}{\sigma_C}, \qquad (2)$$

where $\langle g \rangle_E = \frac{1}{N} \Sigma g_{i\,E}$ and $\langle g \rangle_C = \frac{1}{N} \Sigma g_{i\,C}$ are the



(a)



(b)

Fig. 4a and b. Learning gain distribution for the FBD (left) and CLM (right) mL resources.

averages of the student relative learning gains for the experimental and control groups, respectively, and σ_C is the standard deviation of $g_{i\,C}$. For the sake of consistency, before computing $\langle g\rangle_E$ and $\langle g\rangle_C$ we removed those students with values of $g_i < -1$ from the sample as well as those unusual students with $Pre_i = 100$, which yielded indefinite g_i values. There were 12 such students in our original sample (N_{tot} = 645), yielding final values of N_{E} = 248 and N_{C} = 166 for the FBD mL resources and N_{E} = 116 and N_{C} = 103 for the CLM mL resources.

We present our *ES* results in Table 3, which are close to 0.3 both for the FBD and CLM mL resources. According to Clark & Mayer [40], these values only indicate that using mL resources with the experimental group tended to improve their comprehension and ability to solve specific problems related to the selected topics, as measured by the individual pre-test and post-test scores.

4.3 Comparison of means using t-Student

We performed a *t*-test to the individual student relative learning gains of the experimental and control groups (g_i) to better estimate the significance of the difference of their means. This comparison was undertaken considering as null hypothesis H_0: $\langle g\rangle_E = \langle g\rangle_C$ versus the alternative hypothesis H_1: $\langle g\rangle_E \neq \langle g\rangle_C$. Our results are also shown in Table 3, where we can see that the difference in the means is meaningful for the FBD mL resource (p = 0.0025) while it is only relatively meaningful for the CLM mL resource (p = 0.045). These results are significant, especially considering all the possible biases that may have been present during our implementation process, as commented in Section 4.7 below.

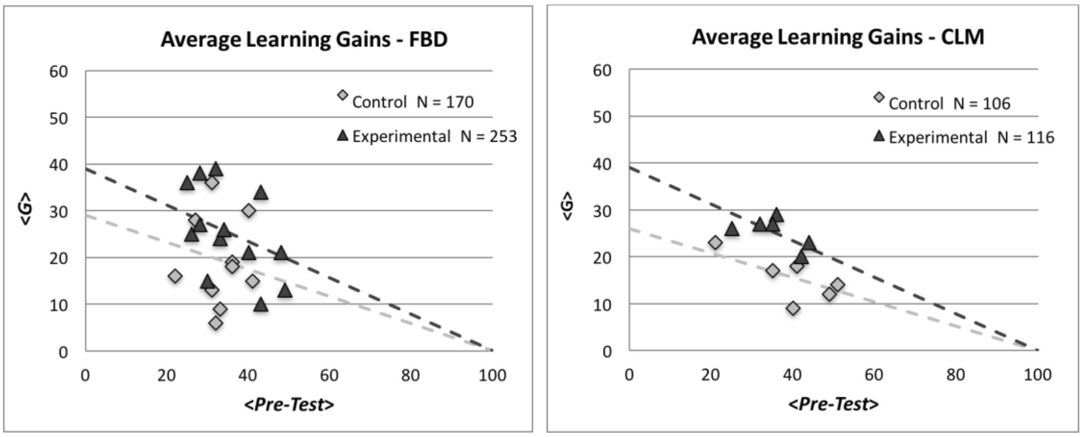
Table 3. Effect size (ES), experimental and control group relative mean differences and their *p*-values for the FBD and CLM mL resources

	FBD	CLM
ES	0.29	0.26
$\langle g\rangle_E - \langle g\rangle_c$	0.12	0.11
p-value of difference (*t*-Student, 2 tails)	0.0025	0.045

4.4 Hake diagrams

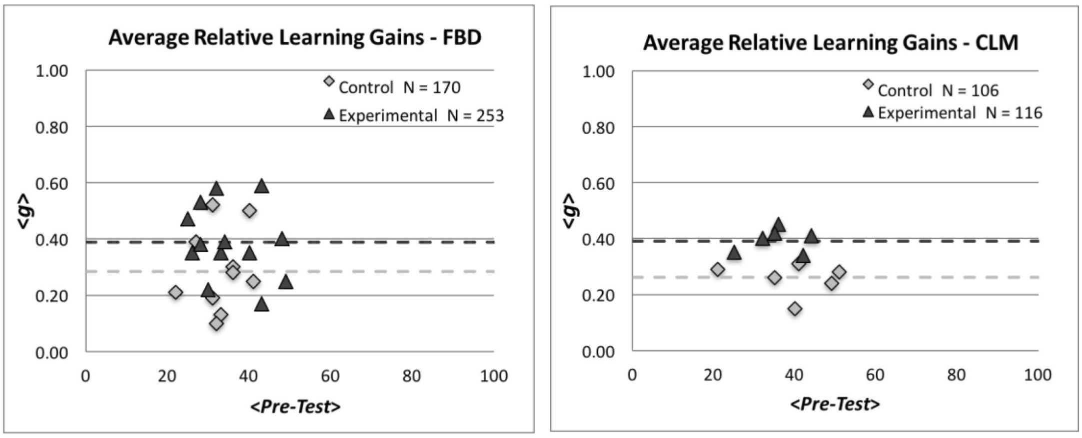
The comparisons that we have shown using *ES* or the hypothesis test with *t*-Student do not take into account the "*pre-test effect*". That is, it is not appropriate to compare two groups for which the difference in their average pre-test score may hide or artificially increase the impact of a given educational resource on student performance. One way to take into account the pre-test effect is by using the diagrams proposed initially by Hake [38], which consider that there is a linear relationship between the group learning gain $G = \langle Post\rangle - \langle Pre\rangle$ and the average pre-test $\langle Pre\rangle$ for a number of academic sections. This condition is equivalent to considering that the group relative gain (g) is equal to the slope of the straight line $G = -g\langle Pre\rangle + 100g$, over the whole pre-test range, as implied by Equation (1) above.

In Fig. 5a and b, we show the group learning gain G versus the average pre-test $\langle Pre\rangle$ for the FBD and CLM mL resources, respectively, where each dot represents a section. In each case, the broken lines correspond to the weighted average group relative learning gains (g) given in Tables 1 and 2 for the experimental and control sections. As we can see in both diagrams, most of the experi-



(a) (b)

Fig. 5a and b. Group learning gain $G = \langle Post \rangle - \langle Pre \rangle$ vs. average pre-test $\langle Pre \rangle$ for the FBD (left) and CLM (right) mL resources. The straight broken lines correspond to the weighted average group relative learning gains (g) for the experimental and control sections, as given in Tables 1 and 2.



(a) (b)

Fig. 6a and b. Group relative learning gain g (as defined by Equation 1) vs. average pre-test $\langle Pre \rangle$ for the FBD (left) and CLM (right) mL resources.

mental groups fall above the line corresponding to the control groups. Likewise, most of the control groups fall below the line corresponding to the experimental groups.

In Fig. 6a and b, we show the group relative learning gain g (Equation 1) versus the average pre-test $\langle Pre \rangle$ for the FBD and CLM mL resources, respectively, where each dot represents a section. The horizontal broken lines represent the weighted average values for the experimental or the control groups. Although there is dispersion in the results (especially for the FBD), we can see that the experimental and control groups tend to occupy different regions on the diagrams. For the FBD mL resource, the experimental group has $g_E = 0.39$, while the control group has $g_C = 0.29$, which corresponds to a 34% increase. On the other hand, for the CLM mL resource, we found $g_E = 0.39$ and $g_C = 0.26$, which corresponds to a 50% increase.

4.5 Regression analysis

The analysis of the results by means of Hake diagrams is not based on a probabilistic approach. Therefore, we performed a hypothesis test with a linear regression using the model:

$$G = \beta_0 + \beta_1(Pre) + \beta_2(Exp) + \varepsilon, \quad (3)$$

where G is the learning gain on a 1–100 scale, *Pre* is the pre-test and *Exp* is a dummy variable used to distinguish between students in the control and experimental groups. $Exp = 1$ if the student belongs to the experimental group, and $Exp = 0$ if the student belongs to the control group.

We analyzed the data using the software *Eviews-3.1* considering the whole cleaned sample ($N = 633$) of individual student pre-test and post-test data, regardless of the section and semester. Our regression results are shown in Table 4, where we show our

Table 4. Linear regression parameters results

FBD	$G = 37.9 - 0.567\ Pre + 7.61\ Exp$ (0.000) (0.000) (0.001)	$N = 414$ $R^2 = 0.252$
	$g = 0.380 - 0.004\ Pre + 0.126\ Exp$ (0.0172) (0.000) (0.001)	$N = 414$ $R^2 = 0.077$
CLM	$G = 41.7 - 0.616\ Pre + 5.19\ Exp$ (0.000) (0.000) (0.053)	$N = 219$ $R^2 = 0.312$
	$g = 0.476 - 0.006\ Pre + 0.081\ Exp$ (0.000) (0.000) (0.106)	$N = 219$ $R^2 = 0.113$

estimated β_0, β_1, and β_2 values in each case according to Equation (3). Below each β value, we also indicate in parenthesis its corresponding *p*-value. We also include the number of students used in the regression analysis and the corresponding R^2 values.

After verifying the absence of autocorrelation errors up to second order (Breush-Godfrey), the absence of heteroscedasticity (White), and residual normality (Jarque-Bera), we found, as expected, that the learning gains *G* are negatively related with the pre-test to a good level of significance ($p < 0.001$). The results of the diagnostic tests were very favorable for CLM. However, the regressions for FBD were carried out using the "White's Heteroscedasticity Consistent Covariance" option due to minor issues detected in complying with the Homoscedasticity assumption.

Our linear regression analysis for the FBD mL resource indicates a learning gain *G*, 7.6 points higher for the experimental group ($Exp = 1$) than for the control group ($Exp = 0$). In the case of the CLM mL resource, the difference is 5.2 points in favor of the experimental group. For the relative learning gain *g*, the differences between experimental and control groups are +0.13 and +0.081 for the FBD and CLM mL resources, respectively.

Our linear regression analysis indicates that the relative learning gains *g*, have a slight dependence on the variable *Pre-test*, contrary to the assumption that these *g* values are constant over all the pre-test range as it is implicit in the Hake's diagrams.

Although not shown in Fig. 5a and b, we also analyzed linear regression fits to the whole data for *G* vs. $\langle Pre \rangle$, both for the experimental and control groups. For the FBD mL resource, we found that the line for the experimental group was always above the line for the control group for any value of $\langle Pre \rangle$. However, for the CLM mL resource, we found that these two lines intersect each other at about $\langle Pre \rangle = 50$, suggesting that the use of the CLM mL resource was more beneficial for students with a poor previous knowledge of this physics theme, that is, with relatively low $\langle Pre \rangle$ values as compared to students with higher $\langle Pre \rangle$ values.

4.6 Negative learning gains

An attention-grabbing result found in this study is the fact that some students showed negative learning gains (G_i), that is, their post-test grades were *lower* than their pre-tests (see Tables 1 and 2). This is an unexpected finding given the fact that both experimental and control groups had time to practice with the corresponding physical concepts using the mL resources or equivalent printed resources, respectively, during the time period between the administration of the tests. As commented below, most likely, these students were not engaged in their learning activities and/or did not take them seriously. In any case, it is interesting to note that for the FBD mL resource, the percentage of students that had *negative* individual learning gains in the experimental group is only 5.9% as compared to 18% in the control group. For the CLM mL resources, we found a similar trend with percentages of 8.6% and 18% for the experimental and control groups, respectively. These results show that this unwanted effect is much lower (about 40%) for the experimental group than for the control group, as would be expected.

4.7 Sources of data biases

There are several sources of possible biases that may smooth out the effect the mL resources may have on student outcomes, as measured by our pre-test/post-test assessment tool. The sources of uncontrolled parameters include (a) real variations in different course sections in a given semester and/or different semesters and (b) uncontrolled differences in the process of applying the pre and post-tests between the different sections and semesters (we were careful, however, to give the same amount of time for both the pre-tests and post-tests to the experimental and control groups), and finally (c) uncontrolled natural changes in the students' attitude and preparedness at the time of taking the pre and post-tests. These factors could also explain those students having negative learning gains mentioned above.

The external variables that we explicitly controlled in order to reduce bias in our data sample included (a) selecting sections to be the experimental and control groups in a random manner each semester, (b) having the *same* professor lecturing both the experimental and control groups within a given semester, (c) grading all the pre and post-tests using the same, well-defined rubric for each of the test items, and (d) having the pre and post-tests graded by the same professor. As a stability measurement for the grading process, several of the pre and post-tests (about 20%) were also graded by another professor using the same rubric. As expected, the average grade for a given test assigned by one professor was nearly the same (within ± 2%) as the grade assigned by the other.

Finally, with respect to the possible correlation between a student's previous academic record and his/her individual learning gain, we looked for any possible correlation between the student's individual learning gain and his/her final course grade, both for the experimental and control groups. We found that they did *not* correspond in any case. This result suggests that the differences we found between the experimental and control groups are *not* due to differences in the students' previous academic performance and skills. However, this result is arguable since the final course grade also includes each student's performance in other course activities such as weekly assignments, mid-term exams and collaborative small-group assignments.

4.8 Perception questionnaire

We present the combined results of our perception questionnaire in Fig. 7a–d. We obtained $N = 45$ student responses for the AD2009 semester, $N = 76$ student responses for the JM2010 semester and $N = 82$ student responses for the JM2015 semester. Quite interestingly, the results for the final JM2015 term were very similar to the corresponding ones for the previous terms. In the questionnaire, we used a 5-level Likert scale which ranged from "Total agreement" on one extreme to "Total disagreement" on the other. For the sake of clarity, we have grouped the student responses into only three bins (a) Total agreement or agreement (A), (b) Neutral (N), and (c) Disagreement or Total disagreement (D) in the results given below.

It can be seen from Fig. 7a–d that most students agree that: (a) the specific mL resources studied in this work (FBD and CLM) helped them to better understand the corresponding concepts (A: 67% vs. D: 11%); (b) mL resources promote problem-solving skills (A: 61% vs. D: 16%); (c) mL resources promote independent learning (A: 53% vs. D: 22%), and (d) overall, the use of mL resources is useful for learning Physics concepts (A: 63% vs. D: 13%). These results suggest that, in general, students agree that the use of mL resources is useful in supporting their learning.

Additionally, the students from the three semesters were invited to freely comment on the types of activities they would recommend to be implemented as mL resources. The integrated results for the three semesters are shown in Fig. 8, where it can be seen that 48% of the students would like the teachers to provide more videos that explain class topics or provide solved examples. This means that students find online resources in which the instructor explains key concepts presented in the classroom as well as guided examples showing them the procedure and steps used in solving a particular exercise to be very useful and helpful. On the other hand, 42% of the students suggested that their instructors design mL resources that include interactive features that could reinforce and promote their learning, for instance: videos with student interaction, games, simulators, virtual labs and

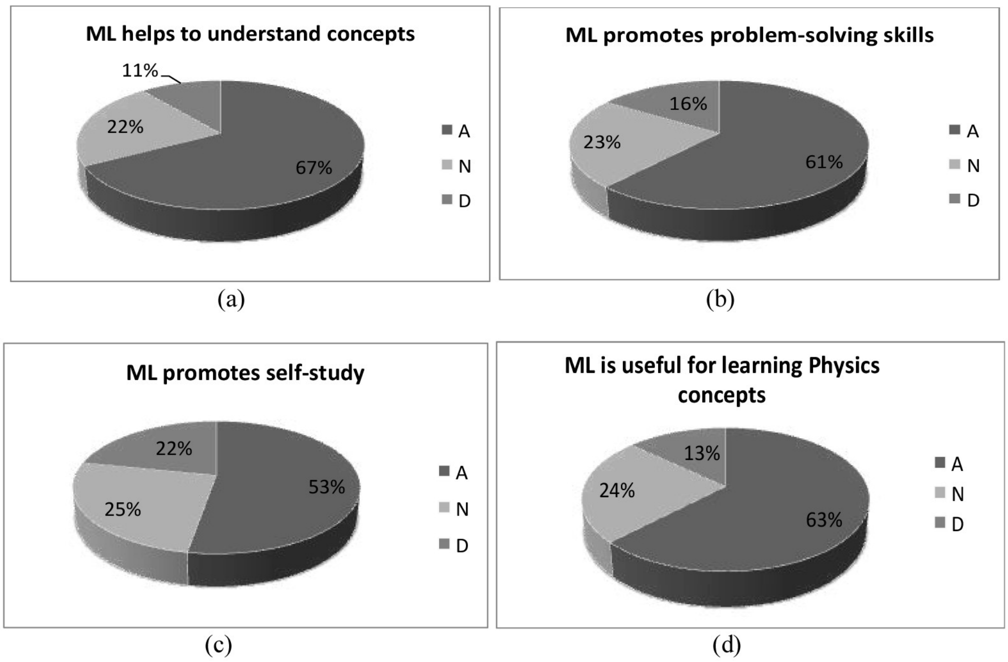


Fig. 7a–d. Combined student perceptions about mL resources for the AD2009, JM2010 and JM2015 terms for 4 selected questions within the questionnaire, where A = total agreement or agreement; N = Neutral and D = disagreement or total disagreement.

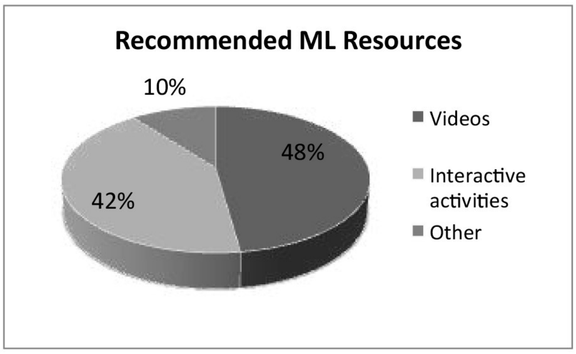


Fig. 8. Recommended types of mL resources.

quizzes. This is an important guideline for instructors when planning the design of mL resources for their courses. It is necessary to engage our current generation of students by using more appealing and meaningful resources and applications, so they can get the most out of these resources.

Finally, the remaining 10% of the sample proposed that other additional resources such as online resources from major editorials like McGraw-Hill or Pearson that often accompany their eBooks and SmartBooks as well as other educational multimedia online resources be included in the course.

It is worth noting that the overall perceptions from the AD2009 and JM2010 semesters were very similar to those from the JM2015 semester, in spite of the boom in the use of technology and electronic devices between these two time periods. This finding indicates that students from both time periods were able to distinguish between resources aimed to foster their learning—such as those presented in this work—and online material intended solely for entertainment. Students these days recognize that academic resources do not need to be as appealing and ludic as those designed for entertainment, but rather they should offer the user clear and accessible explanations, as also discussed by [41].

4.9 Final remarks

Our results suggest that the incorporation of multimedia resources outside the classroom does not necessarily have, by itself, a strong impact on student performance. This may reflect the fact that current student generations are increasingly exposed to multimedia material in their everyday lives via their "inseparable pocket-friends" (their smartphones and/or tablets), so that the inclusion of educational online resources is just a natural and unavoidable step in their learning process inside or outside of the classroom.

Most teachers today know that mobile devices can be a major distractor during class time if they are not used properly. The challenge now for the digital professor is to design and implement ex profeso activities using different educational apps and the Web, both in and outside the classroom, so as to engage the students in a positive and productive way. Some studies in literature have addressed this issue, in particular, [25] reported that students who learned concepts through games performed worse than those who had a traditional, lecture class. However, this is still a current debate since other authors have argued that the opposite is true, at least for children [42–44], teenagers [45], or adults [46].

5. Conclusions and future work

The main goal of this paper was to measure the impact the use of online educational resources may have on student performance. We have presented a long-term 6-year study regarding the influence of three mL resources, designed to help understanding Physics concepts related to dynamics and conservation of linear momentum, on student learning outcomes and problem-solving skills. We gathered data for $N = 645$ undergraduate engineering students from Tecnológico de Monterrey, Campus Ciudad de México by means of a field study based on homogeneous pre and post-test assessments. Our data analysis allowed us to compare student learning gains in randomly-defined experimental and control groups.

Our results indicate that the experimental group obtained learning gains (G) 7–10 points higher (on a 0–100 scale) than the control group, with differences of means p-values in the 0.002–0.04 range. We found effect size (ES) values in the 0.26–0.29 range, which is relatively small, however. Our linear regression analysis also indicates a small but statistically significant learning gain 5–8 points higher for the experimental group than for the control group.

We applied a questionnaire designed to ascertain student perception of the use of mL resources with academic purposes and received overall very positive responses. The students commented that they would like to have more mL resources implemented in their courses, reflecting the fact that we cannot rely only on traditional lecturing. Rather, a blended learning or hybrid approach is needed. The students also asked for interactive online resources in which they could play an active role in their learning process, for example: games, interactive videos, simulators or quizzes. As such, the design of these interactive learning resources must be an important component of every current teacher's agenda.

Certainly, the use of ICTs in education has become a necessity in current instructional practice. The challenge now is to develop appropriate educational methodologies and strategies for technological resources both in and outside of the classroom to engage students in a more complete, meaningful and life-long learning experience. We believe this is the pending task awaiting instructors at all educational levels. We trust that the experiences and conclusions derived from this study will be helpful as guidelines to professors and educators interested in developing and applying mL resources as a vital part of the learning process.

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